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FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

Department of Civil Engineering

The feasibility of implementing advanced metering technology in high income areas in South Africa

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Dedication

I would like to dedicate the completion of my thesis to the following people:

First, I would like to dedicate this thesis to my Lord and Saviour Jesus Christ without whom, this would not be possible. He has taken me through tough times. Given me strength when I had none left and showed me love I cannot fathom, grace I will never merit and mercy that goes beyond logic.

I also dedicate this thesis to my parents; Sammy and Agnes Mburu. They have shown unconditional love and support even when I asked a lot from them. They have been very understanding, very supportive and when need be, disciplinarians.

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Abstract

Water is an important natural resource and a building block to all life on earth. However, substantial increase in water demand and consumption has led to numerous nations, including South Africa, to face water scarcity. Improved water demand management strategies and water monitoring approaches are imperative. In South Africa, it's a legal requirement for all water supply points to be metered. Currently, water flow is primarily measured by conventional meters. However, substantial developments have been noted in the last two decades where conventional meters with added capabilities (such as communication capabilities) added have been introduced. These meters are known as advanced water meters. These capabilities offer functions such as leakage detection and more immediate consumption feedback. However, advanced meters also have significant disadvantages such as require high start-up capital and are susceptible to higher failure rates than conventional meters. It remains to be seen if advanced metering technology is an appropriate technology to be adopted in South Africa. Due to the different dynamics of South Africa's income level groups, the metering application and effects will differ for each income level group. Therefore, the purpose of this study is to investigate the feasibility of implementing advanced metering systems in high income areas in South Africa.

An evaluation framework was developed to gauge the viability of implementing advanced metering systems on four performance criteria; technical, economic, environmental and social. The composite indicator framework template was selected as it was not tailor made for a specific reason and could be adapted for this research. The necessary framework input parameter data were acquired from practitioners in the field through questionnaires and from literature. Due to lack of advanced metering case studies in South Africa (except for prepaid meter), literature from developed countries were used as proxies. The input data entailed details of the current metering system, advanced metering system and new conventional metering system with the later used as a control for comparative purposes. The typical high-income scenario was derived from typical input data. For each input parameter, there were value ranges from the low parameter value to high parameter value. These ranges were used to conduct the sensitivity analysis on the framework to access critical input parameters to the success or failure of implementation

Implementing advanced metering systems in high income areas in South Africa was found to be less economically viable than conventional meters. This is due to the lack of needed infrastructure for advanced metering as well as high initial capital costs and high operating costs. Advanced meters however proved to be more environmentally viable than conventional meters as they offered higher reduction in consumption. However, the manner in which faulty batteries are disposed could lead to environmental damage. Social factors were considered negligible for high income areas as revolts to introduction to new meters arises from financial constraints that

those meters might induce. Further research with more South Africa based case studies and smaller scale advanced metering systems has been recommended.

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Notations and Abbreviations

Abbreviation	Definition
AMR	Automatic Meter Reading
AMI	Advanced Meter Infrastructure
AMM	Advanced Meter Management
AWWA	American Water Works Association
BMC	Billed Metered Consumption
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
IWA	International Water Association
OECD	Organisation for Economic Co-operation and Development
O&M	Operational and Maintenance
WEF	World Economic Forum
WDM	Water Demand Management
WRC	Water Research Commission
WWF	World Wide Fund



1 INTRODUCTION

1.1 Background to the research

Water is one of the most important natural resources, second only to oxygen (Chaplin, 2001), and a building block to all life on earth. Its described by Postel et al. (1996) as a commodity that has no substitute for most of its uses. During the 2002 World Summit on Sustainable Development in Johannesburg, Nelson Mandela alluded to this when he was quoted as saying: “Among the many things I learnt as a president was the centrality of water in the social, political and economic affairs of the country, the continent and the world” (Msangi, 2014).

Water makes up approximately 71% of the earth’s surface (Shakhashiri, 2009; Williams, 2014) of this, less than 3% is fresh water (Mehta, 2000; Jenerette & Larsen, 2006) and only approximately 0.3% of global water is available for human consumption (Mehta, 2000; Fry et al., 2006). Though fresh water is renewable, with the exception of ground water, there is a finite amount of fresh water available for human consumption (Postel, Daily & Ehrlich, 1996). The growth of global water demand and consumption of a limited resource has led numerous cities and nations across the world to face a state of water scarcity (Jenerette & Larsen, 2006).

According to 2017 report by the World Economic Forum, water scarcity is ranked 3rd most concerning global risk in terms of impact (WEF, 2017). Though the term ‘water scarcity’ is widely used, there are a lot of misconceptions around its definition. Water scarcity is often viewed in absolute and rigid terms, such as the total globally available amount of water is running out (Seckler, Molden & Barker, 1999). However, this viewpoint is problematic as it serves to simplify a complex problem. The complexity of water scarcity is due to the various attributes that contribute to its existence. As such water scarcity is described as the unavailability of water when and where people need it (Seckler, Molden & Barker, 1999; Fry et al., 2006).

South Africa is a water scarce country with approximately 98% of the water in the country termed to already be allocated (Hedden & Cilliers, 2014). In 2013, South Africa was characterised as the 30th driest country in the world due to low and variable rainfall in conjunction with high evaporation rate (DWA, 2013). However, the leading factor to the increasing water scarcity in South Africa is the vast increase in water demand. In 2012, despite South Africa having a lower water per capital than arid nations such as Botswana and Namibia, it has a higher water consumption per capital (at 235 litres per person) than the world average (173 litres per person) (Mckenzie, Sigalaba & Wegelin, 2012).



Based on 2014 data, Hedden & Cilliers, (2014) stated that South Africa total water demand and total water supply was estimated at 15.6km^3 and 14.6km^3 of water per annum respectively. This was noted as a state of over-exploitation of water resources due to the gap between water demand and water supply of 1km^3 . Using the International Futures (IFs) global forecasting system, Hedden & Cilliers, (2014) demonstrates that in 2030, South Africa's demand-supply gap is expected to increase. Due to vast projected increase in Rural-Urban immigration and rising income levels as well as increase in agricultural activity, water demand in 2030 is projected to rise to 19.5km^3 per annum. Water supply is also expected to rise to 16km^3 due to use of renewable-energy production, increase in desalination and better water resource management. The demand-supply gap, however, increases from 2014 to 2030 by 2.5km^3 . This indicates further stress on an already over-exploited resource. This could lead to consequences of environmental resilience of aquatic ecosystems and the reliability of water supply for human consumption (Hedden & Cilliers, 2014).

Water governing bodies such as municipalities are charged with the increasingly challenging task of meeting the growing demand for water and the vital need to preserve the limited available water resources and supply. According to Brooks, (2006), water utilities have two options when presented with a higher water demand; increase the water supply input to meet the rising demand or reduce water consumption through water demand management and leak reduction. However, due to limited water resources and the cost incurred with attaining and supplying more water, the latter option has often been the more favoured. Hedden & Cilliers, (2014), further support this as they state that the high average per capita water consumption in South Africa can be reduced through means of reducing the volume of non-revenue water lost and better water consumption monitoring.

Water demand management (WDM) is briefly defined as the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource (Kayaga & Smout, 2007). However, prior to implementing any WDM strategy, it is critical to have knowledge of the amount of water being supplied and consumed. This is done with the use of water meters.

Water meters are instruments used for recording the quantity of water passing through a particular outlet. Water metering is vital as it applies the principle of "to measure is to know". This means that knowledge of what is happening with the water supply system can be obtained which is key to properly managing this resource (Van Zyl, 2011).



1.2 Problem statement

In South Africa, it is a legal requirement that all water supply points be metered. This makes water meters very crucial and pivotal to service provision within communities and the country as a whole. Currently water flow is measured mainly by conventional water meters. Conventional meters are defined as the mechanical water meters from which the readings are taken on site, monthly.

For a long time, conventional meters were a sufficient means for measuring water supply and consumption. However, with the development of improved water consumption monitoring, water consumption could be attained at a short interval as compared to monthly readings. Also, with conventional meters, early detection of on-site leakages was impossible. Over the past two decades, substantial developments in metering have been made, leading to the introduction of water meters with added functionality known as advanced water meters.

Advanced meters are defined as conventional meters with added electrical components that can record the consumption patterns at regular intervals and communicate this back to the service utility as well as to the consumer. Advanced meters have added capabilities such as data storage and communication (Britton, Stewart & O'Halloran, 2013). These meters are designed to provide better and more efficient services in areas where conventional meters have become inefficient. They also provide new services that could not be provided by conventional meters. However, with regards to durability, advanced meters are still inferior to conventional meters as they are not as robust and more susceptible to tampering and vandalism. Advanced meters are also associated with high implementation and maintenance cost as compared to conventional meters. Despite this, advanced meters are seen as the better solution to the increasing need of better consumption monitoring and leakage detection due to their added capabilities. However, it still remains to be seen if it's an appropriate technology to be adopted in South Africa.

1.3 Motivation for the research

Advanced water meters are fairly new into the water metering market. Although research has been done on the capabilities and effect of advanced meters, there is limited research on the applicability of advanced meters in South Africa. As such, there is limited literature that offers a framework to assess the collective impact of implementing advanced meters to South African communities.

The Water Research Commission (WRC) sponsored a research project to determine the state of the art in developments and application of advanced water metering to allow South African municipalities to understand the available technology and how to best utilise it. Due to



the different dynamics of South Africa's income level groups, the applications and impacts advanced metering technology would not same for all communities in South Africa. As such, this project was further classified into the applications of advanced metering in high income areas (taken up by the author of this dissertation) and low-income areas (taken up by the author's colleague, Malunga Masaobi). For this research, high income areas are defined by the monthly income per household. Due the assumptions made in this thesis about high income areas, such as little community volatility, high income areas is defined as a household with a monthly income that exceeds R50 000 (Masemola, van Aardt & Coetzee, 2011).

Judging from the literature, advanced water meters are in theory more beneficial than conventional meters due to the added capabilities they provide; however, that does not necessarily mean they will be more practical if implemented. Therefore, this research has been set up to explore the effects of advanced water metering on a high-income community as compared to the currently used metering systems. For this purpose, this research will look at the technical, economic, environmental, and social effects of advanced water metering as compared to conventional water meters.

1.4 Research objectives

The research objectives are as follows:

- to determine the range of functionality available and being developed for advanced water metering
- to document case studies of successful and failed implementation of advanced water meters, including social perceptions and impacts
- to develop an evaluation framework for advanced water meters
- to conduct sensitivity analysis to access which input is crucial to the success or failure of implementation of advanced metering systems.

1.5 Scope and limitations of the research

This research will be strictly looking at the application and effects of advanced water meters in high-income areas. From a South African perspective, data required from field test were scarcely available. As such data was estimated and motivated based on literature found on the application of advanced metering technology in developed countries.



As this research requires data on a vast number of variables, numerous assumptions were made to simplify research conducted. These assumptions were primarily made on the individual typical parameter and parameter ranges used. Other assumptions were made to reduce the scope of the research. One such assumption was that social parameters such as income level and unemployment rate were considered negligible in high income areas.

1.6 Overview of the study

The research study begins with Chapter 2 which presents a review of the literature on existing conventional metering systems, technologies and the components required as well as the advanced metering systems and technology and components required for the system. This chapter also considers the development history of both types of meters and at the benefits and drawbacks of both these systems.

Chapter 3 gives an overview of the case studies acquired on advanced water meters implementation in high-income areas. Here, the conditions prior to implementation and the drivers leading to the implementation are elaborated on; the implementation stage and the documented results are also described.

Chapter 4 describes the development of evaluation frameworks and in detail describes the two main components of the framework; validation phase and evaluation phase. Validation phase is the first aspect of the evaluation framework chapter where project aims and objectives for selecting a type of advanced metering option are outlined. This serves to match an advanced metering option with the main objective for implementation. Thereafter, the chapter presents the development of the evaluation phase of framework. This includes the criteria it examines, the input data that is required, the recommended output that should be obtained and explanation of the typical results generated from the typical input parameters previously outlined.

Chapter 5 discusses sensitivity analysis performed on the framework input parameters. This serves to access which input parameter has the biggest impact and effect to the success or failure of the implementation of advanced metering systems. The sensitivity analysis also serves to access the relationship of changes to the input with changes to the output generated.

Finally, Chapter 6 discusses the conclusions that can be drawn from the research study as well as recommendations made for the process taken, alternatives that could be used and best approach for future research.



2 LITERATURE REVIEW

2.1 Introduction

This chapter discusses the current knowledge and literature on this subject matter. This chapter will expound on topics for both conventional and advanced meters such as the development of water meters, market drivers for implementation of metering scheme, components and classification of meters, types of water meters and benefits and drawbacks of both meters.

Lastly, the different types of evaluation frameworks will be discussed as a framework layout will be used to access both conventional and advanced metering schemes.

2.2 Conventional Water Meters

2.2.1 Introduction

Conventional meters are water meters that are used to measure and record water consumption in order to bill the consumer (based on their monthly consumption), assess the water balance of the system and identify failures in a network (Puleo et al., 2014).

This chapter will elaborate on the history and classification of conventional metering, drivers for the use of conventional meters, discuss the different types and mechanisms of conventional meters, and illustrate the benefits and drawbacks of using conventional meters.

2.2.2 History and classification of conventional water meters

This section discusses the development of conventional meters and metering principles that are still utilized in modern water metering.

2.2.2.1 Introduction to water metering

Water metering has occurred for thousands of years as early civilizations realized the need to monitor the limited resources. Early agricultural civilizations were situated in regions where rainfall and runoff was easily collected (Gleick, 2000). However, these sources became inadequate to supply the needs of rapidly growing cities. These cities then required advances in the sciences of civil engineering and hydrology as water supplies had to be brought in from increasingly distant sources (Gleick, 2000). One of the advances made was the means of measuring the water intake, or water metering.

For about 3,000 years, water was distributed equally from the Gadames Oasis in North Africa through the means of ‘water metering’. This ‘water meter’ was a pot with a small hole and a string tied to it. Water was collected from a spring using this pot and then emptied in a farm or land through a water drain. The string in the pot would be pulled and water would be allowed to run for 3 minutes. Each land proprietor would get a set number of pots of water allowed to them based on the ruling of the tribal water commission. A man at the spring was tasked with the responsibility of providing each land with water. When it was the turn for a land proprietor to get water came, a piece of wood would be thrown into the drain and the owner would open the sluice gates to allow water to flow. (AWWA, 1999).

Roman civilization is another example of early civilization that was noted to illustrate ‘water metering’ practices. For nearly half a century until 313 B.C., Roman citizens were content with drawing water from the Tiber River and springs. However, the expeditious growth of their city also caused their current water sources to become limited; this resulted in technological advances being made to solve this problem. Water pathways and pipes known as aqueducts were constructed in 34 A.D. to transport water from the mountains and hills to Rome. These were one of the initial advancements into the development of water distribution systems. A water commissioner named Frontinus was involved in the implementation of these aqueducts and noted that there is a need to measure the flow. To perform this task, adjutages, as shown in Figure 2-1, were used as meters. Flow was measured based on the capacity it stored. This however proved to be inadequate as it did not consider the flow rate (AWWA, 1999).

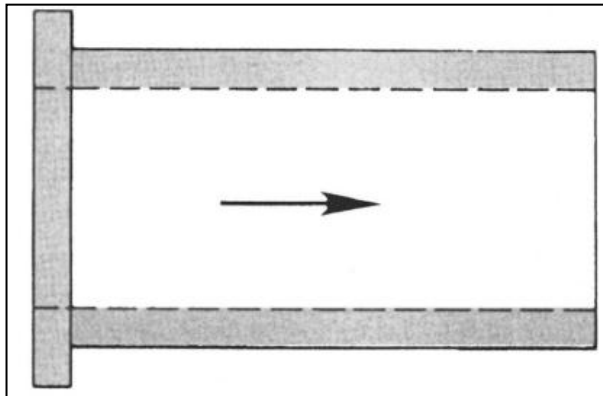


Figure 2-1: Roman Adjutages- This is a bronze tube of a specific capacity (AWWA, 1999)

Though only the two above examples are noted, water metering proved to be important for the development of early civilizations. The proceeding section discusses the development of metering technology and capabilities.

2.2.2.2 The Pitot tube

One of the early developments in water metering came through the invention of the Pitot tube. In 1730, a French engineer known as Henri Pitot used a vertical glass tube with the short, 90° tip at the lower end pointing upstream to determine whether there was a relationship between the rise of water in the tube and the velocity of flow. Two years later, through the inclusion of a second vertical tube (as illustrated in Figure 2-2 below) meant to measure the static head, Henri Pitot discovered that the height to which water rose in his tube was proportional to the square of the stream velocity. On the same year, Pitot's discovery coincided with a publication by a Swiss mathematician, Johann Bernoulli, where he stated the fundamental relationship of energy head to velocity squared of water through pipes (AWWA, 1999).

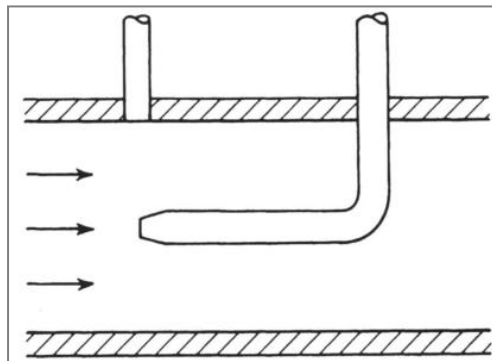


Figure 2-2: Pitot tube and the second vertical tube (Crainic, 2012a)

After approximately 125 years, a French engineer known as Henry Darcy modified the tube and thus improved the accuracy of the static-head readings and reduced the oscillations of the water columns. The outcomes of the Pitot tube aided the understanding of how to measure the velocity of water flow and as such contributed to the advancement of water meters. In recent times, the pitot tube is used to obtain temporary measurement of flowrate in large pipes (AWWA, 1999).

2.2.2.3 Classification of modern meters

Conventional water meters are categorized based on the mechanism used to measure the flow of water through the meter. These meters are first classifications into two main groups:

- Mechanical meters
- Non-mechanical meters

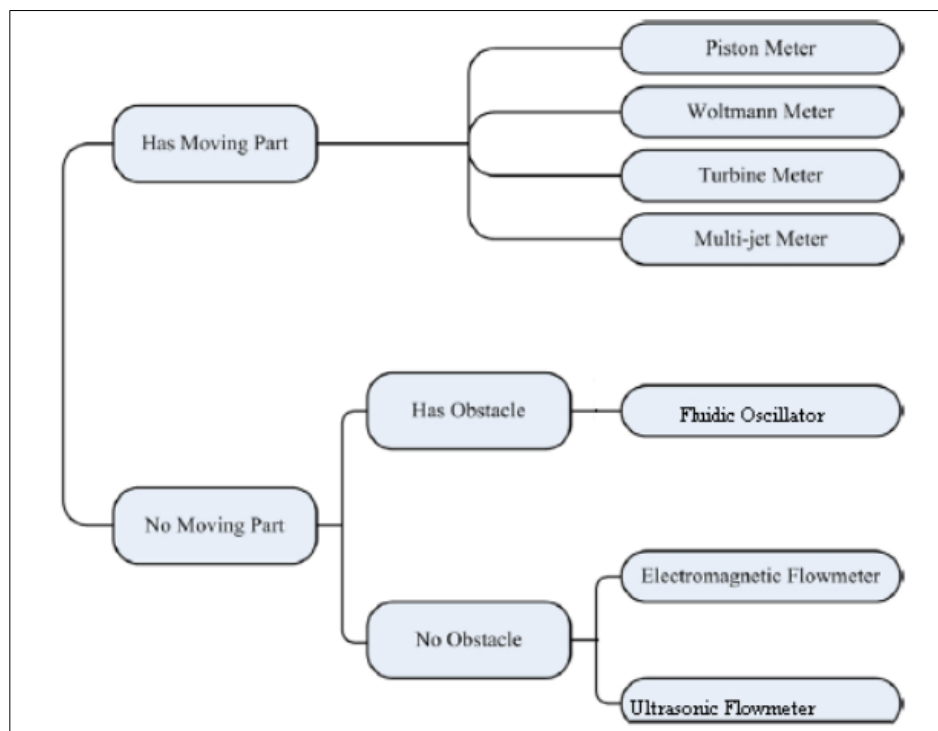


Figure 2-3: Classification of conventional meters (Crainic, 2012a)

2.2.2.4 Mechanical meters

In modern times, water meters are classified as either mechanical meters with moving parts or non-mechanical meters (Crainic, 2012a). Prior to the invention and development of non-mechanical meters, mechanical meters were in development and in use. This section serves to illustrate how mechanical meters were developed. Mechanical meters are further classified into displacement meters and velocity meters. This section commences with the development of displacement meters followed by the velocity meters

Though liquid meters were previously in use, the first water meter deployed was an *oscillating piston water meter* believed to be developed in 1850 by an American mechanical engineer, Henry R. Worthington. This meter comprised of two cylinders and plungers with inlet and outlet ports. These meter components were set up so that as the water in the inlet cylinder was discharged by the piston, the outlet cylinder would be filling up. However, due to the pulsation induced by the piston movement as well as high friction losses, the meter readings were highly inaccurate. In 1842, a single piston, double acting meter was developed to tackle this issue. In this meter, water was directed through a small valve either above or below the piston cylinder of a known volume (Crainic, 2012a). The rise and fall of the piston would also drive the counting mechanism and recording. Numerous designs and improvements were made between



1871-1900. Earlier designs had impractical features such as moving valves and partial parts to start and stop during each cycle of measurement. However, in 1884, the first practical oscillating piston meter was developed and issued by an American engineer called Lewis H. Nash which comprised of the shape and movement of modern oscillating piston meters (Crainic, 2012a).

The *nutating disk meter* is a mechanical meter that was first issued between the 1887 and 1888. However, the concepts and mechanism of this meter originated from the mechanism of a hydraulic engine constructed in 1830 (Crainic, 2012a). This engine consisted of a horizontal axis with the engine casing connected to a disc. When steam was allowed into the engine through the control of valves, the engine axis would rotate causing the engine casing to rotate around the disc. In 1854, this concept was miniaturized used in a nutating piston pump and then in 1887, adapted into water metering (Crainic, 2012a). In the early stages of the nutating disk meter development, manufacturers found problems with hard rubber discs breaking at fast flows. One solution to this problem was a thrust roller to control the circumferential thrust of the disc in its movement and preventing jamming. An alternative approach was to mould a metal reinforcement into the hard rubber disc section of the nutating piston meter. However, both solutions needed the disc thin and chamber walls to minimize spillage. This lead to the modified nutating meter manufactured in 1892 by an American engineer, George B. Bassett. The design he implemented is similar to the nutating piston meters used today with an added reinforcing plate in the modern models (Crainic, 2012a).

Turbine water meter, invented in 1790 by Reinhard Woltman, a German water engineer, was the first practical velocity meter deployed used to measure air and water flow (AWWA, 1999; Crainic, 2012a). The meter, as illustrated in Figure 2-4 below, consisted of a very light waterwheel operated by the current and carrying on its axis a worm (a gear in the form of a screw) for actuating gearing and a totalizer. The rate of flow was computed from the rotations during a given time period (AWWA, 1999). In 1850, advancements on the turbine meter were by Werner von Siemens, a German inventor and industrialist (Crainic, 2012a). When in operation, water would enter the measuring chamber of the meter through the angularly positioned inlets. This, however, caused the flow to affect one side of the vanes of the rotor at a 90° angle. Smaller inlets entering the measuring chamber at an opposite angel were made to prevent the rotor from spinning too fast. This meter was substantially different from the typical turbine meter in which water would strike the blades of a rotor at approximately 45° (AWWA, 1999; Crainic, 2012a).

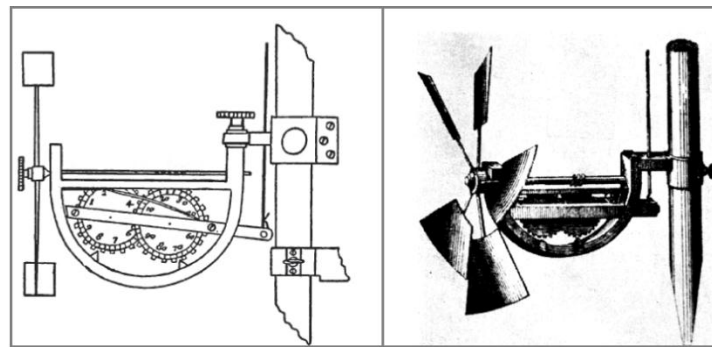


Figure 2-4: Original form of the Woltman meter (Crainic, 2012a)

With the advent of magnetic drives, some models have returned to the horizontal rotor spindle, which gives lower pressure loss. The first of the modern turbine meters, now referred to as Class II Turbine Meters, was introduced to the market in 1965. The new Class II turbine meter was capable of operating over a much wider flow range than earlier turbine meters which have been offered by manufacturers since the 1920s. The new horizontal, in-line, high-velocity turbine meters are built of more modern materials. The new materials for bearings, coupled with low-mass, self-lubricating, low-friction gearing in the registers and gear trains, permit the back loading on the metering elements to be reduced, thus providing improved metering accuracy, range sensitivity, and longevity for this meter (AWWA, 1999).

The invention of the *venturi meter* in 1886 by Clemens Herschel made a major contribution to the measurement of flowing water under pressure (AWWA, 1999). The tube is based on a principle discovered a century earlier by the Italian engineer Giovanni Battista Venturi, that the flow of the liquid through a converging pipe results in a gain in velocity and a lowering of pressure, whereas the reverse is true in a diverging pipe (AWWA, 1999). Figure 2-5 illustrates the components of a venturi meter.

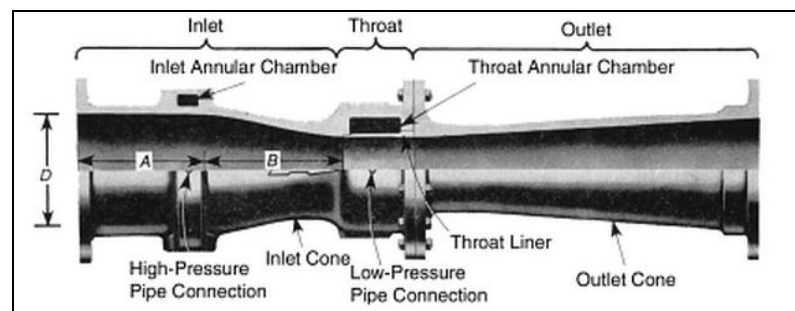


Figure 2-5: Components of a Venturi meter (AWWA, 1999)

Multi-jet meter is another type of velocity meters that was first deployed in Germany in 1867 by the German conglomerate company Siemens-Halske (now known as Siemens AG)



founded by Werner von Siemens and Johann Georg Halske, a German mechanic. The multi-jet meter was manufactured in two basic designs: the wet and dry register models. Due to the magnetic drives for meters, the dry model became the more prevalent meter.

2.2.2.5 *Non-mechanical meters*

Despite the adequate performance and low cost provided by mechanical meters, they have limitations arising from the principles that govern their mechanism such as the deterioration rate of the meter accuracy with increasing age. These limitations accumulate and translate into overall increased maintenance cost of owning a meter and lost revenue for the utility. These accumulated costs incurred exceed the original cost of the meter. Developments were then made into non-mechanical meters with electronic registering and these meters were found to not be hindered by the limitations of the mechanical meters. This section therefore serves to elaborate on the developments made to non-mechanical meters.

Electromagnetic water meters originated from the principles of Faraday's Law discovered by Michael Faraday in 1832. Faraday began experiments to detect the flow velocity of a river through detecting the voltage induced by the earth's magnetic field. However, this approach failed due to short-circuit caused by the river bed and additional flow signals induced by electrochemical and thermoelectric signals (Shercliff, 1987). After almost 20 years, voltage induced in the English Channel was measured. Following this development, the first practical breakthrough was achieved in 1917 when the speed of ships could then be detected through measuring with electromagnetic force. In 1930, the first electromagnetic flowmeter design was introduced as these meters were used to measure the flow of copper sulphate solution through circular glass pipe (Shercliff, 1987). In 1952, the first practical electromagnetic flow meters were manufactured by the German company KROHNE Messtechnik GmbH and introduced to the public. In 1997, Kent Meters Limited imbedded a battery into the electromagnetic meters (Shercliff, 1987; Crainic, 2012b).

The principle of the *ultrasonic water meters* was conceived from the Doppler technology first developed in 1959 by Shigeo Satomura. In 1963, a Japanese company known as Tokyo Keiki introduced the first industrial ultrasonic flow meter. It became apparent however that the Doppler ultrasonic flowmeters couldn't be used in clean liquids as this method was originally designed for measuring blood flow (Crainic, 2012b). As such, in the 1990s transit time (also known as time of flight technology) ultrasonic technology was introduced and was suitable for clean liquid. Figure 2-6 below illustrates the transit time ultrasonic meter.

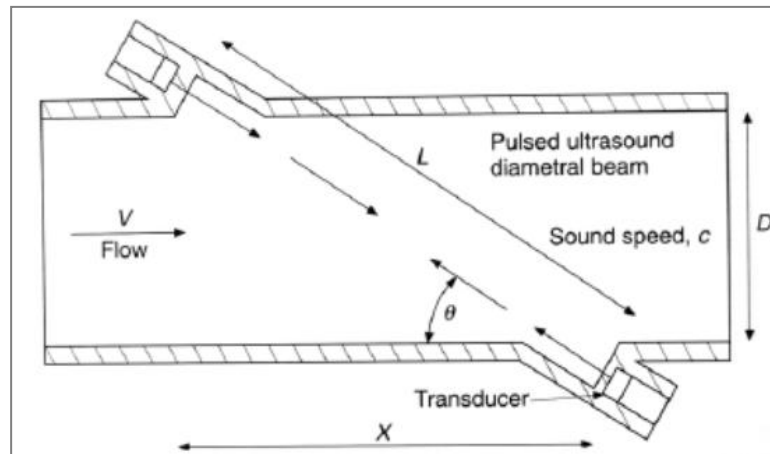


Figure 2-6: Transit time venturi meter (AWWA, 1999)

2.2.3 Drivers for the implementation of conventional meters

2.2.3.1 Introduction

The drivers that support and led to the use of conventional meters as to the alternative of using no water meters are fourfold and are as follows:

- Equity
- Water efficiency and losses
- Economic benefits
- System management

2.2.3.2 Equity

“Comprehensive water metering provides an equitable basis for charging consumers based on the amount of water that they consume” (Van Zyl, 2011). Charging for the amount of water used not only raises income that can be used to better develop water services, it also makes consumers more cautious of how they consume water and furthermore allows for subsidization of water services to consumers that need it (Van Zyl 2011).

2.2.3.3 Water efficiency and losses

The introduction of water meters has made consumers more alert about their water consumption as they are able to monitor, on a monthly basis, the amount of water they use. Consumers are thus given the incentive to change their lifestyle in order to reduce consumption or make better use of their resources (Van Zyl 2011). These changes also result in a positive impact on the environment.



Since readings can now be collected and analysed, municipal engineers can estimate the level of water loss in a water supply system and develop methods to mitigate the issues. They can also identify illegal connections to the system (Van Zyl, 2011).

2.2.3.4 *Economic benefits*

As stated earlier, one of the direct benefits of water meters is that income can be collected from consumers based on their water consumption. It directly affects the municipal's revenue. As such a well-kept and accurate water meter system improves the municipals income. The means used to determine the cost of water consumption are water tariffs (Van Zyl 2011).

2.2.3.5 *System management*

The knowledge acquired from water meters on the amount of water flowing through the water distribution system proves to be very crucial. Enhancements can be made and maintenance carried out to the water distribution system based on the water flow knowledge. One such change could see pipes in distribution system being changed or added to allow for the appropriate steps to be taken that would to meet rising demands and generate the optimum income. Data acquired from a well operated metering system can allow management to make more informed decisions on capital investment, staffing, maintenance and other components of the water supply system. (Van Zyl 2011).

2.2.4 Components of a conventional meter

2.2.4.1 *Introduction*

Conventional meters generally comprise of four basic components. These are:

- Sensors
- A transducer
- A counter
- An indicator

2.2.4.2 *Sensors*

A sensor is defined as a device that can detect the flow passing through a water meter. Sensors can either detect the volume of water directly or indirectly (Van Zyl 2011).



Meters with sensors that can detect the volume of water directly are known as volumetric or positive displacement meters as they count off the ‘little packets’ of water passing through the meter (Van Zyl 2011).

Other meters that detect volume indirectly are known as velocity or inferential meters as they first measure the flow velocity and then convert velocity to volume (Van Zyl 2011).

2.2.4.3 Transducer

A transducer is defined as a device that converts a signal in one form of energy to another form of energy (Agarwal 2005). For water meters, it is a device that transfers the signals picked up by the sensor to the meter (Van Zyl 2011). In water meters, the transducers used are mostly magnetic. However, the use of these transducers generates friction which reduces the meter accuracy and, in time, causes wear.

2.2.4.4 Counter

The counter is the section of the water meter that accumulates the flow readings it receives via the transducer. The counter records all the flow that has passed through the meter since its manufacture (Van Zyl 2011).

2.2.4.5 Indicator

The indicator acts as the user interface of the water meter and displays the information required and obtained from a water meter.

2.2.5 Types of conventional meters

2.2.5.1 Rotary piston meter

A rotary piston meter is a type of volumetric meters that measure ‘packets’ of water by using a rotating cylindrical piston. The meter consists of two chambers for the outlet and inlet flow and a cylindrical piston that divides the two chambers (Van Zyl 2011).

As the water flows into the outlet chamber, the cylindrical piston moves to the inlet chamber and creates a small compartment where water flows into the meter. The piston then moves in a clockwise direction and increases the size of the outlet chamber while reducing the size of the inlet chamber. The water then flows through the outlet chamber and the whole cycle begins again. This is demonstrated by Figure 2-7 below (Van Zyl 2011).

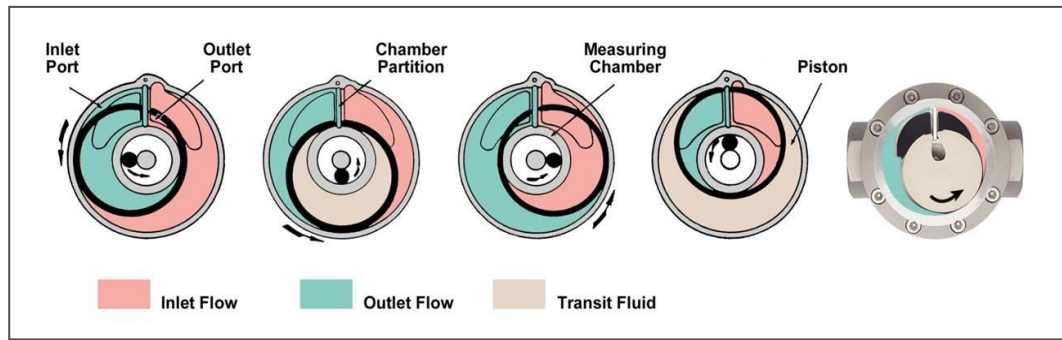


Figure 2-7: Rotating piston tube as water flows through the chambers (adapted from Van Zyl, 2011)

The amount of water transported by each rotation is exactly the same. Therefore, the volume that passes through the meter is determined by the number of rotations.

Rotary piston meters (and other positive displacement meters) are commonly known for their combination of accuracy, long life, and moderate cost. They are the ideal meter of choice for most domestic applications. Since they are volumetric meters, they are not sensitive to the velocity of the flow; therefore, the meter can be placed close to bends or pumps (Van Zyl 2011). Figure 2-8 shows an example of a rotary piston meter.



Figure 2-8: Rotary Piston Flow Meter DN15-40 (adapted from Hydrometer)

2.2.5.2 Single-jet meters

Single-jet meters are a type of inferential meter which uses a single flow stream to move the impellor with radial vanes. The impellor and vanes act as the sensors. The rotational speed of the impellor is converted into flow speed and registered on the meter (Van Zyl, 2011). Figure 2-9 illustrates an example of a single-jet meter.

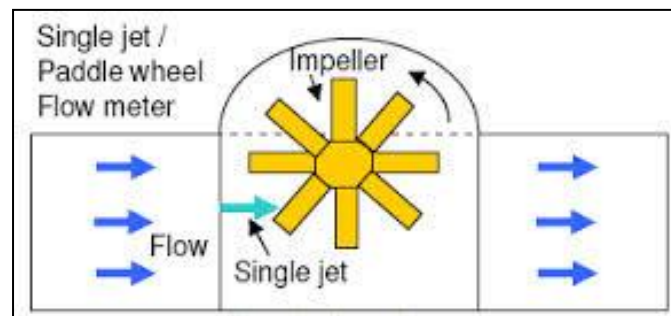


Figure 2-9: Diagram illustrating the workings of a single jet

When implementing the single-jet meter, it is critical for the accuracy of the meter that the path of the water through the meter is precisely controlled. This is because single-jet meters are manufactured to adhere to strict tolerance. Though it is an inferential meter, the single-jet meter is not greatly affected by being installed near bends. However, moving parts at the connection can hinder the accuracy of the instrument (Van Zyl 2011).

Single-jet meters are mostly used in low-volume situations. Areas with a small diameter for domestic uses are ideal (Van Zyl 2011). Figure 2-10 is an example of single-jet meter.



Figure 2-10: Examples of single jet meters (adapted from Van Zyl 2011)

2.2.5.3 Multi-jet meters

The multi-jet meter uses multiple ports to create multiple jets of water against an impeller whose rotation speed depends on the velocity of water flow. This makes the force better balanced as compared to single-jet meters. This makes multi-jet meters more accurate at low flow rates (Van Zyl 2011).

Multi-jets are usually used for domestic applications. Though multi-jets are similar to single-jet meters in construction, multi-jet meters are more cost effective for diameters greater than 20mm. Figure 2-11 shows an example of a multi-jet meter.



Figure 2-11: Examples of multi-jet meters (courtesy of Elster Kent, Sensus and Itron)

2.2.5.4 Woltmann meters

Woltmann meters are also inferential meters that use impellers and helical vanes. As the water flowing through the Woltmann meter, the impellers cause it to rotate. The rotation is then used to determine the flow rate (Van Zyl 2011).

There are two types of Woltmann meters, namely horizontal and vertical ones. Horizontal meters have inlets and outlets directly in line with the pipeline and the axle of the helical vane is parallel to the flow. Vertical Woltmann meters turn the flow by 90° to the impeller and then turn it back to the original flow direction (Van Zyl 2011).

Woltmann meters have a wide array of uses but are mostly used to measure the consumption of bulk users. Figure 2-12 shows an example of a Woltmann meter.



Figure 2-12: Examples of Woltmann meters (adapted from Sensus and Itron)



2.3 Advanced water meters

2.3.1 Introduction

Advanced meters are defined as water meters that have added functionality as compared to a conventional meter. Advanced metering was first developed for electricity supply and utilizes; therefore, most of the written literature on advanced metering refers to electrical energy. However, the components, technologies and policies are the same for all advanced metering applications.

Therefore, the following topics will be discussed:

- History of advanced meters
- Development and market drivers
- Components of an advanced meter
- Communication service and infrastructure
- Communication technologies
- Features of an advanced meter
- Types of advanced water meters
- Benefits and drawbacks of advanced meters.

2.3.2 History of advanced water meters

In the early 2000s, globally the metering market and water utilities recognised the increasing need for attaining detailed and near-real-time data and analytics to improve better water management strategies and deliver more predictive and proactive services (Cutler, 2010). The foundation of this movement was the development of advanced metering infrastructure (AMI) technology. AMI offers a remote and constant two-way data link between utilities, meters, and consumers. Communications are delivered through numerous methods and technologies such as power line communications (PLC) and cellular transmissions (Cutler, 2010). These technologies are further expounded in chapter 2.3.6.

Through a communication infrastructure of concentrators, repeaters and gateways, data is passed between meter and utility and funnelled into analytical software that can immediately set off pre-determined alerts (Cutler, 2010). This is can also be used to produce accurate bills and consumption patterns of neighbourhoods. Apart from monitoring the current status of water



consumption, more regular data can better contribute towards hydraulic modelling to help better predict outcomes and changes in water distribution.

Hydraulic modelling and network monitoring can be used by utilities to make evidence-based network investments and undertake upgrades. Utilities can also send information back to the meter to perform remote upgrades, reset alert parameters, shut off water supply during change of tenancy or reduce water flow for unpaid accounts (Cutler, 2010).

2.3.3 Development and market drivers

2.3.3.1 Introduction

Investments and development in advanced water networks are being driven in part by the increased availability, reliability, and functionality of the underlying technologies. However, there are numerous strong driving factors that are leading to an increase in advanced metering implementation in the water supply sector. These are:

- **Water scarcity-** This is one of the main driving factors in the development of advanced water meters. The rise in demand for water could soon exceed the existing water sources especially with the pressures felt from climate change and historic over-use. As such there is a need for more efficient use of the available water, i.e. a reduction in water wastage (Woods & Strother, 2013). (Fróes Lima & Portillo Navas, 2012) state that there is a need for natural resources to be better managed; they propose that this could be done through better monitoring of water consumption and relaying of information through the use of advanced meters.
- **Aging infrastructure-** As numerous water supply infrastructures, have been in place for long periods of time, these are frequently in need of an upgrade. In addition, ongoing technological development also leads to current infrastructures becoming redundant and no longer meeting the consumers' needs and expectations. This is a big challenge for water utilities as a lot of funds need to be channelled towards renovations and construction. The US alone estimates that this procedure will require trillions of dollars for upgraded drinking water infrastructure over the coming decades (Woods & Strother, 2013).
- **Leakage and non-revenue water-** Another challenge facing the water utilities is water and revenue lost to the utility due to on-site leakage and non-revenue water consumption. Water utilities are estimated to lose up to 40% of the water in their networks through leaks in the system. In addition, water is lost through theft and



faulty metering as well as through inefficient operation of the network. The World Bank estimates that the cost of global NRW is at \$141 billion per year (Kingdom, Liemberger & Marin, 2006). In Australia, (Britton, Stewart & O'Halloran, 2013) conducted experiments to investigate the effectiveness of communication interventions to the repair of household leaks.. It was found that the installation of advanced water meters reduced water leakage by about 89%.

- **Utility operations savings-** Reducing the operation costs related from manual meter reading has been a driver for the implementation of advanced water meters in North America and elsewhere. Utilities are now looking to advanced water networks to reduce maintenance and repairs costs and improve asset management (Woods & Strother, 2013).
- **The water-energy nexus-** Water and energy supplies are interdependent. This is because water is needed in all phases of energy production and in turn energy is required to extract and deliver water. However, managing both resources optimally and efficiently has been a challenge (U.S. Department of Energy, 2014). Water utilities are looking to use advanced meters to help reduce energy costs and contribute to broader energy efficiency and greenhouse gas (GHG) reduction targets being set by cities, governments and international bodies (Woods & Strother, 2013).
- **The impact of urbanization-** The urbanization of the world's developing nations is having an impact on the global landscape. Between 2010 and 2050, almost 3 billion additional people will require urban drinking water and wastewater services. An investment in basic water infrastructure is the primary requirement to meet these needs; however, advanced water networks can also play a role. According to the United Nations, between 250 million cubic meters and 500 million cubic meters of drinking water is lost to leakage and other causes in many of the world's megacities each year. As increase in urbanisation will result in increase in water demand, adequate monitoring of water consumption, more accurate accounts of water supplied and adequate leakage detection will become more paramount. Cities in the developed world could use advanced meters and their capabilities to develop better water management strategies and combat the challenges on the water sector arising from urbanization.



2.3.4 Components of an advanced meter

2.3.4.1 Introduction

As previously described, any water meter with added functionality is considered an advanced meter. This means that advanced meters have the same components as conventional meters and extra components that give them added functionality. The components of the conventional meters have already been discussed. Therefore, this section aims to investigate the components that give advanced meters added functionality. These components are:

- **Transmitters-** A transmitter is the core element for the communication capability of an advanced water meter. Transmitters are devices that transmit water meter readings to a remote location in the form of radio waves. For advanced metering applications, the typical range of a transmitter using wireless radio is about 1 kilometre (Blom, Cox & Raczka, 2010)
- **Data loggers-** Data loggers are used to store the data and send interval data (Blom, Cox & Raczka, 2010). Data loggers can be adjusted to log time at different time intervals. One immediate advantage of interval data logging is that it simplifies leak detection. Leaks are identified by noticing sustained constant water flow over a duration of time (Blom, Cox & Raczka, 2010).
- **Gateways-** A gateway is a device that receives signals from one or more data transmitting devices and relays the information to a distant location. Gateways act as large loggers and can store multiple data points and transmit them in packets to the retailer. This process of data storage and transmission decreases the need to incessantly relay data over large distances (Blom, Cox & Raczka, 2010).
- **Consumer interfaces-** A consumer interface is an implement that allows a person to interact with a piece of technology. An in-home display, a water bill, and an online web portal are all examples of consumer interfaces that could be made available to a consumer to view their water consumption data (Blom, Cox & Raczka, 2010).

2.3.5 Communication services and infrastructure

2.3.5.1 Introduction

Advanced meters consist of added communication capabilities that allow for information to be collected from the water meters and, if necessary, feedback to be relayed back to the water meters. These abilities allow for an improved level of functionality and interaction between the



different bodies involved in the supply chain (Haney, Jamasb & Pollitt, 2009). This makes communication a critical aspect of advanced metering technology (Lipošüak & Boškoviü, 2013).

As such, different communication infrastructures have been put in place to enable information to travel on different networks. The networks involved are:

- Home Area Networks (HAN)
- Local Area Networks (LAN)
- Wide Area Networks (WAN).

These communication infrastructures consist of the networks stated above as well as the bodies involved in the water supply chain (i.e. water meters, home display, water utilities etc.) and include the following:

- Automatic Meter Reading (AMR)
- Advanced Meter Infrastructure (AMI)
- Advanced Meter Management (AMM).

2.3.5.2 Automatic meter reading (AMR)

Automatic meter reading (AMR) simply implies that the readings are collected remotely from the water meter without a person physically accessing the meter. It is a one-way system where data is collected from the meter but no feedback is sent back. The simplest form of AMR is a handheld meter reader that can collect data from the water meter through a temporary Radio Frequency (RF) link while the user is in a car or walking in a street (Electa et al., 2008).

AMR can also be implemented through permanent communication infrastructure between the meter and the supplier. This is accomplished by using wireless and wired communication technologies. Both the simple and the advanced forms of AMR allow for accelerated meter readings and accurate billing (Haney, Jamasb & Pollitt, 2009).

In the UK, forms of AMR were installed in sites that used half-hourly metering so that suppliers can base billing on accurate consumption. The duration taken for information to be available to consumers depended on the individual suppliers. According to a 2005 survey by the Carbon Trust, it was found that the time it took energy suppliers to make data available varied from 24 hours up to one month (Carbon Study, 2007).

Figure 2-13 illustrates the concept of how AMR systems work. Data is firstly collected and stored in the data loggers. The information is then transmitted through the transmitter by either

using RF waves or Wi-Fi signals to the nearest transmitter mast. The mast broadcasts the signal to any of the receivers in the utilities Ethernet (a family of computer networking technologies for a LAN) and it is then transferred to the main server or central computer.

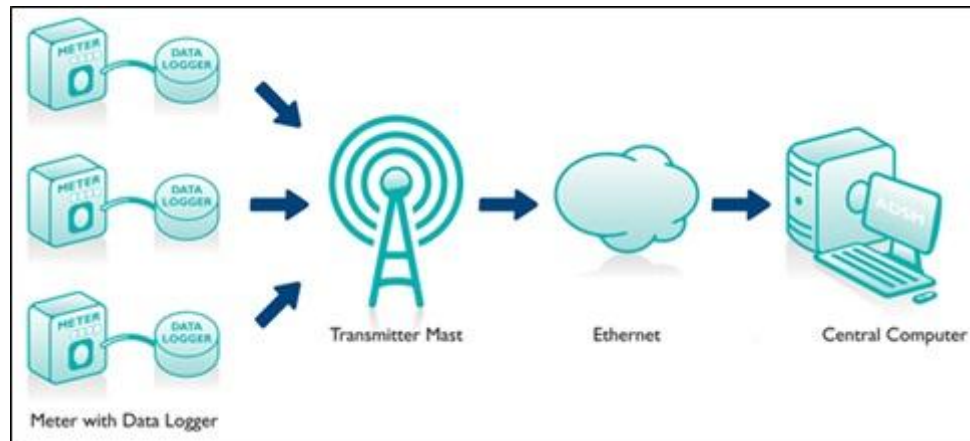


Figure 2-13: Illustrating how an AMR system functions

2.3.5.3 Advanced Meter Infrastructure (AMI)

Advanced metering infrastructure (AMI) is similar to the AMR as it refers to the entire infrastructure of meters, communication networks and data management systems required for advanced information to be measured, collected, and subsequently used. However, unlike AMR, AMI is a two-way communication system. This infrastructure allows the meter to be connected to the supplier, other market actors and even home appliances through the Home Area Network (HAN) (Haney, Jamasb & Pollitt, 2009).

Currently, AMI is the front runner for communication infrastructure in an advanced metering system. Figure 2-14 shows a simplified picture of how the various communication networks link parts of the AMI together. Data is collected locally from the advanced meters and transmitted via a LAN to a data collector. The data collector can then opt to process the data or just transmit it. The data is then transmitted via a WAN to the utility central collection point. At this stage, data can be processed and used for business applications. Since AMI is a two-way process, signals can be sent directly to meters, customer premises or distribution devices.

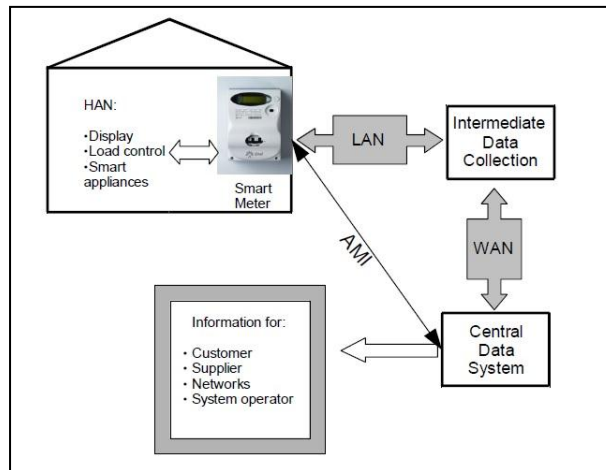


Figure 2-14: Simple representation of Advanced Metering Infrastructure and Home Area Network (adapted from Haney et al, 2009)

In an AMI, the advanced water meter can act as a platform for coordinating with other devices in the home (display devices) and with the customer through the HAN, and with the rest of the electricity system through the LAN and WAN. Figure 2-15 illustrates a form of AMI in a community.

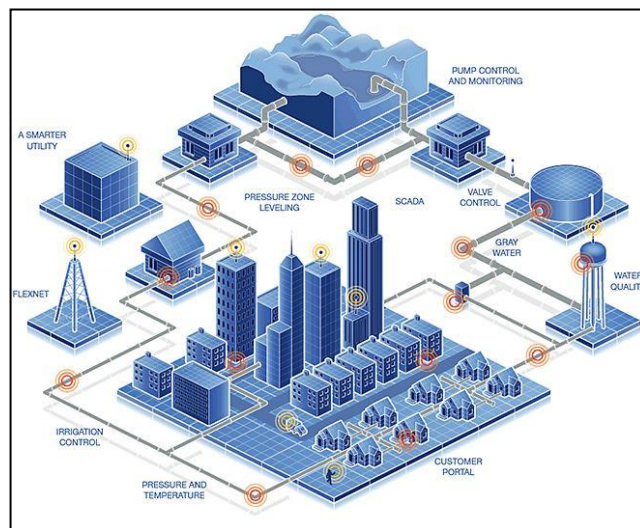


Figure 2-15: Illustration of an AMI system in a community (adapted from Sensus)

2.3.5.4 Advanced Meter Management (AMM)

Advanced Meter Management (AMM) is an extension of AMR with the ability to manage meters remotely. This structure is similar to an AMI as it is a two-way communication process between the meter and the rest of the network. However, unlike with AMI, water meters can be remotely



managed as commands or messages can be sent and uploaded to the meters, and data can be downloaded from the meters (Electa et al., 2008).

2.3.6 Communication technologies

2.3.6.1 Introduction

As previously stated, communication is a critical aspect of water metering and therefore communication systems and infrastructure have to be put in place. However, in order for communication to take place within the systems, communication technologies are needed for transmitting and transferring the information. Various technologies have been developed for advanced meters and they include the following:

- ZigBee communication
- Wireless mess communication
- Radio frequency mesh networks
- Radio frequency point-to-multipoint networks
- Power line communication
- Cellular networks.

2.3.6.2 ZigBee networks

ZigBee is a wireless communication technology that has relatively low power usage, data rate, complexity, and cost of deployment. ZigBee and ZigBee Advanced Energy Profile (SEP) have been rated as among the most suitable communication standards for the advanced grid residential network domain by the US National Institute for Standards and Technology (NIST) (Bennett & Highfill, 2008).

The communication between advanced meters and other intelligent home appliances as well as home displays is very important. ZigBee integrated advanced meters can communicate with the ZigBee integrated devices and control them. ZigBee SEP enables utilities to send messages to home owners, and consumers can access the information of their real-time energy consumption. Figure 2-16 demonstrates the structure of a ZigBee network.

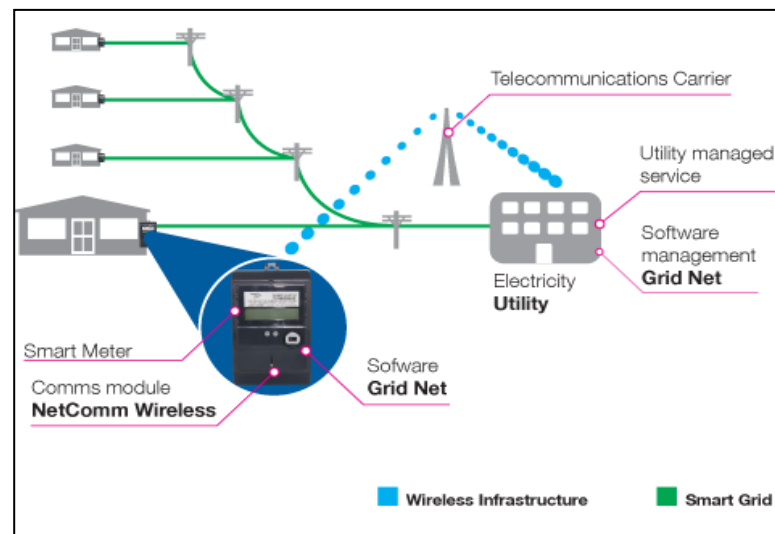


Figure 2-16: Structure of a ZigBee communication network

The advantages of using ZigBee are as follows:

- Robust system
- Low bandwidth requirements
- Low cost of deployment
- Easy network implementation
- Good load control and reduction can be achieved
- Aid with demand response and real-time system monitoring and pricing.

ZigBee networks have the following disadvantages of:

- Low processing capabilities
- Small memory size
- Small delay requirements
- Subject to interference with other appliances.

2.3.6.3 Wireless mesh communication

A wireless mesh network (WMN) consists of mesh routers and mesh clients, where mesh routers have minimal mobility and act as the backbone of WMNs (Akyildiz, Wang & Wang, 2005). Wireless mesh networks can easily, effectively, and wirelessly connect entire cities using inexpensive existing technology. Traditional networks rely on a small number of wired access

points or wireless hotspots to connect users. However, in a wireless mesh network, the network connection is widespread among numerous wireless mesh routers that can communicate with each other to share the network connection across a large area (Akyildiz, Wang & Wang, 2005). WMN has self-healing capabilities as the network allows communication signals to find another router if one router drops out of the network (Güngör et al., 2011).

For a WMN to function, each advanced device is equipped with a radio module. This module enables information to be transferred to a nearby mesh router which in turn can route the metering data through other nearby routers. Each router acts as a signal repeater until the collected data reaches the electric network access point. Then collected data is transferred to the utility via a communication network. Figure 2-17 illustrates the structure of a WMN. WMNs can also be integrated with other networks such as cellular networks through the bridging capabilities of mesh routers (Güngör et al., 2011).

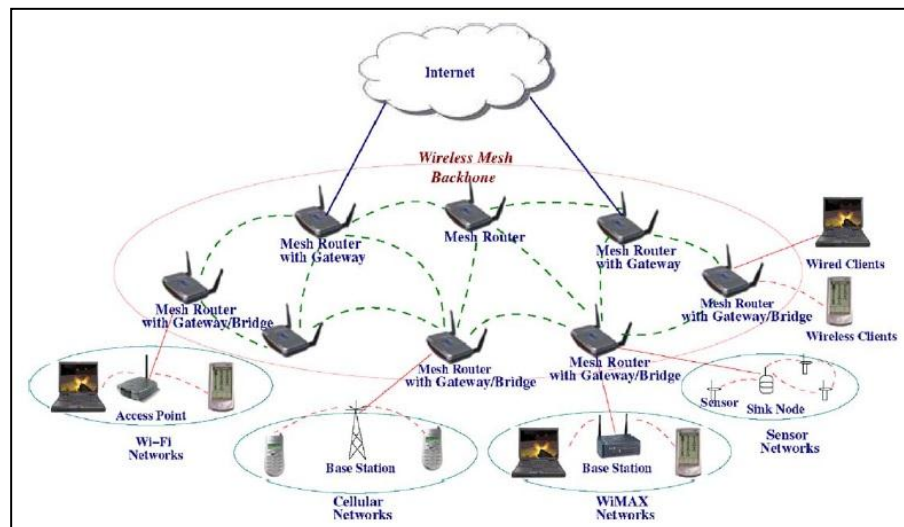


Figure 2-17: Structure of a Wireless Mesh Network (adapted from Akyildiz et al. 2005)

The advantages of using WMN include the following:

- Cost effective solution as WMN operates on existing infrastructure and has dynamic self-organization and self-healing capabilities
- Improved network performance due to the self-organizing capabilities
- Load is adequately balanced within the network
- Widespread network coverage.



The disadvantages of WMN are as follows:

- Fading and interference can easily occur
- Lack of complete coverage due to high meter density in urban areas
- A third-party company is required to manage the network
- High security measures need to be taken.

2.3.6.4 Radio frequency (RF) mesh networks

Radio Frequency Mesh Networks are similar to the Wireless Mesh Networks. The advanced meters act as the router of the network and can communicate with each other in a LAN system. The signals are then transmitted to a collector through a mesh router. The collector transmits the data using various WAN methods to the utility central location (Queen, 2011).

The advantages of using a RF mesh technology are as follows:

- Low implementation costs
- Acceptable latency
- Large bandwidth

The disadvantages of RF mesh technologies include the following:

- Terrain may prove challenging in rural areas (line of sight)
- Cannot cover large distances
- A third party company is required to manage the network (Queen, 2011).

2.3.6.5 Radio frequency point-to-multipoint networks

In a RF point-to-multipoint network, advanced meters communicate directly with a collector, usually a tower. The tower collector transmits the data to the utility central location for processing through different methods (Queen, 2011).

The advantages of a RF point-to-multipoint are as follows:

- There is little or no latency
- Direct communication with each endpoint
- Large bandwidth for better throughput



- Can cover longer distances.

The disadvantage of RF point to multipoint networks is:

- Terrain may prove challenging in rural areas (Queen, 2011).

2.3.6.6 Power Line Communications

Power Line Communication (PLC) is a technology that carries data and transmits electric power on power lines (Kim et al., 2011). Since power lines have being widely established, there is no need to install separate communication lines. Through the power lines PLC can easily be installed and connected to various networks via a backbone network (i.e. the main network that is connected to several local networks (LANs) (TechTerms, 2014). Furthermore, devices can easily be connected into the system by simply plugging into an electrical outlet port. This has lead PLC to be regarded as one of the most suitable and applicable technologies both for remote meter reading systems and automatic control systems to realize advanced metering infrastructure (AMI), which is essential for setting up an advanced grid (Khalifa, Naik & Nayak, 2011).

The following factors affect the PLC properties:

- Choice of frequency
- Choice of propagation speed
- Voltage level carried
- Distance between the two communicating points
- Existence of transformers
- Availability of an electricity grid

Arguments have being raised by (Kerk, 2005) and Soh and Kerk (2005) that a combination of a PLC AMR system and wireless technology is the only solution able to reduce the tariff price and to serve more houses in India and Singapore.

Description of how a PLC system works is explained by Park et al. (2002) and illustrated by Figure 2-18. According to Park et al. (2002), the meters are connected to a PLC modem through a data port. These modems, which are under the same pole transformer, are then connected to a concentration modem. The concentration modem acts as a bridge between the PLC network and a data network. Meters report their measurement when they are polled. The PLC modem buffers the frames until there is an acknowledgement that data has being correctly

received, or otherwise the frame is retransmitted. Throughout this system, there is no evaluation provided (Khalifa, Naik & Nayak, 2011).

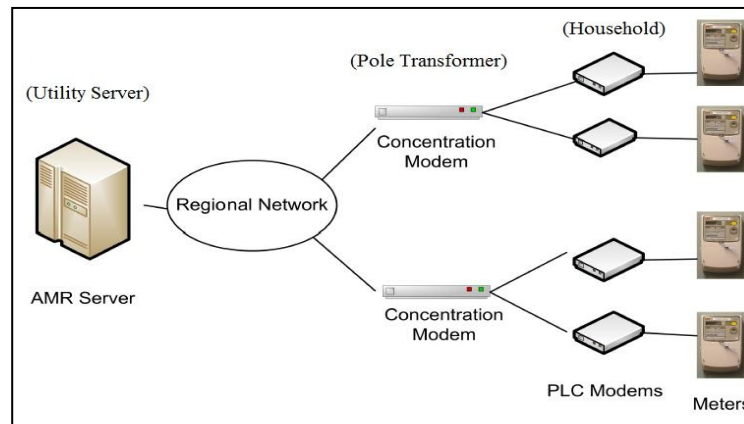


Figure 2-18: Configuration of AMR system using PLC (adapted from Park et al, 2002)

Another example of how PLC is used to transmit measurements was illustrated by Choi et al. (2008) and is shown by Figure 2-19. The system involves various devices and different communication technologies where water meters first transmit their measurements over wireless links to a device called Home Concentration Unit (HCU), which is to be installed in every household. A number of HCUs from different households send the measurements to a device called Data Concentration Unit (DCU). This device sends the metering data in Device Language Message Specification (DLMS) format through a PLC modem to the utility company. Traffic direction is only from the meters to the utility provider.

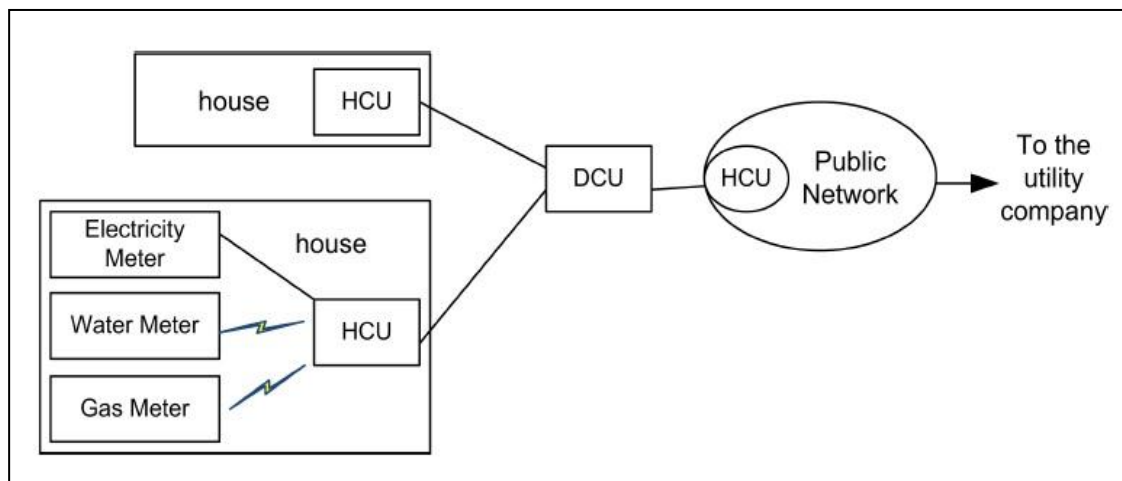


Figure 2-19: An example of a PLC system (Choi et al. 2002)



The advantages of PLC technology include the following:

- Data transmission is secure
- Leveraging the use of existing utility infrastructure of poles and wires
- Improved cost effectiveness for rural lines
- More effective in challenging terrain
- Capability to work over long distances (Queen, 2011).

The disadvantages of PLC technology are as follows:

- Longer data transmit time (more latency)
- Less bandwidth and throughput
- Limited interface with Distribution Automation (DA) devices
- Higher cost in urban and suburban locations. (Queen, 2011).

There are numerous challenges faced by the PLC technology such as:

- Noisy medium
- High signal attenuation
- Susceptibility to interference from nearby devices leading to high loss rate
- Scalability of PLC-AMR system. No work was found showing how much geographical area a PLC network can cover or how frequently the metering data can be reported (Khalifa, Naik & Nayak, 2011).

The PLC technology has already been deployed for broadband services in many countries. However, in certain countries such as Australia, Russia and the United States, such deployments have been terminated. Reasons are the high cost involved and the fact that other means of communication with higher stability and reliability are available (Khalifa, Naik & Nayak, 2011).

2.3.6.7 Cellular network communication

Cellular networks are another alternative means of communication between the waters meters, utilities, and other water supply bodies. Similar to the PLC, cellular networks consist of existing communication infrastructure. This means that the utilities do not have to incur the costs of either installing these infrastructures or for initial operations and implementation. Cellular network solutions also enable advanced metering deployments to spread to a wide area environment

(Güngör et al., 2011). Cellular communication technologies such as 2G, 2.5G, 3G, WiMAX and LTE, are available to utilities for advanced metering deployments.

When a typical data transfer interval of 15 minutes between the meter and the utility is used, huge amounts of data are generated and a high data rate connection is required to transfer the data to the utility (Güngör et al., 2011). For instance, in the UK, T-Mobile's Global System for Mobile communications (GSM) network has been chosen for the deployment of Echelon's Networked Energy Services (NES) system. An embedded T-Mobile SIM within a cellular radio module will be integrated into Echelon's advanced meters to enable the communication between the advanced meters and the back-haul utility. Since T-Mobile's GSM network will handle all the communication requirements for the advanced metering network, there is no need for further investment by utilities into a new dedicated communications network. Figure 2-20 illustrates an example of a cellular network used in an advanced metering system.

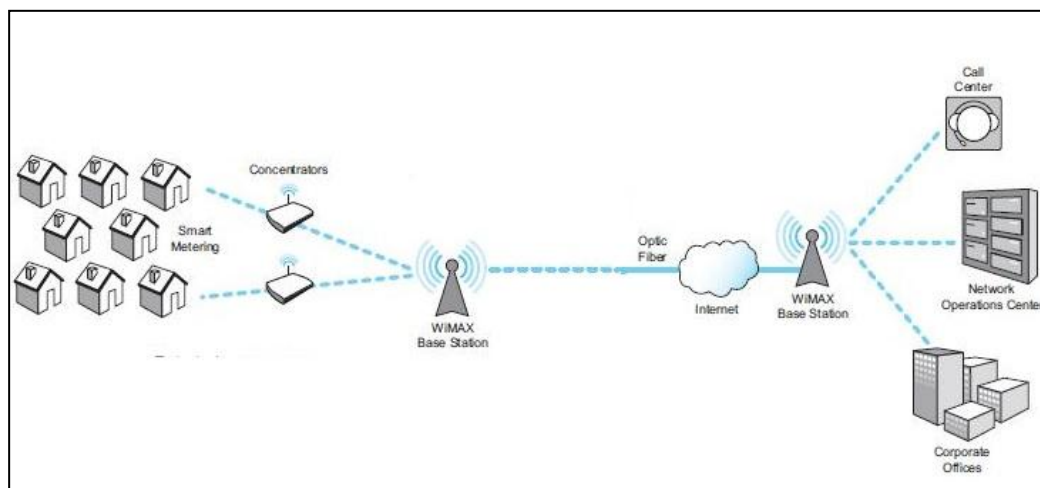


Figure 2-20: An example of advanced metering via cellular connections

Other cellular companies such as Telenor, Telecom Italia, China Mobile, and Vodafone have also agreed to put their GSM network into service for data flow of advanced metering communications. Itron's SENITEL meter is integrated with a GPRS module and communicates with a server running Advanced Synch's Transaction Management System.

Like the GSM, other communication platforms such as Code-division Multiple-Access (CDMA), Wideband Code-Division Multiple-Access (WCDMA), and Universal Mobile Telecommunications System (UMTS) wireless technologies are also used in advanced grid projects. In the US, CDMA is an advanced grid solution introduced by Verizon for the residential utility market. Verizon's 3G CDMA network will be used as the backbone of the advanced grid communications with the Advanced Synch advanced grid solutions. Another US wireless carrier,



Sprint Nextel, signed a partnership with the advanced grid software provider, Grid Net, on a project to provide communication between advanced meters and advanced routers over its 4G wireless network (Güngör et al., 2011).

An Australian energy delivery company known as SP Aus-Net built a dedicated communications network for advanced grid applications and chose to use WiMAX technology as the communication tool. In order for this technology to succeed, WiMAX chips are embedded into the advanced meters and dedicated wireless communication takes place between advanced meters and the central system in SP AusNet's system (Güngör et al., 2011). These examples illustrate the many cases where cellular networking has been used as the communication tool in an advanced metering system.

Cellular networking has a lot of advantages as a means of communication for advanced metering and they are as follows:

- Cost effective as no extra capital costs on constructing the necessary infrastructure have to be incurred
- Widespread coverage where infrastructures and signal masts being in place
- Sufficient bandwidth needed for huge data generation
- Secure data transmissions due to strong security controls in place
- Easily adaptable to any communication infrastructure and network
- Low maintenance costs
- Fast installation features (Güngör et al., 2011).

However, cellular networks also have a number of drawbacks. These include the following:

- Network congestion as cellular networks share with customer markets
- Network performance can decrease in emergency situations
- Hindrances can be caused by abnormal conditions e.g. wind storms (Güngör et al., 2011).

2.3.7 Features of an advanced meter

With all its components and communication capabilities, an advanced meter can perform the following functions:

- To store multiple consumption measurement and to archive this data



- To send measurement registers periodically (at least monthly) as well as on demand
- To undergo remote modification of tariffs and tariff periods
- To send automatic fraud alarms
- To process capacity
- To store data of the capacity
- To send and receive signals from a remote transmitter and receiver
- To control meter functions (e.g. valves) remotely (Electa et al., 2008).

2.3.8 Types of advanced water meters

2.3.8.1 Introduction

As previously stated, advanced meters are defined as any water meter that has added functionality. This means, therefore, that there are various types of advanced water meters with different functionalities for different situations. These are the following:

- Prepaid meters
- Simple digital meters
- Upgraded mechanical meters
- Remotely read meters

2.3.8.2 Prepaid meters

A prepaid meter is a water meter that uses an in-built control system to control water consumption based on the amount of water paid for. A consumer pays for the amount of water upfront from a teller and is given an input code which is then entered through the prepaid meter user interface. The processor then reads the code and turns on the valve to allow through the volume of water that was purchased. Once the volume exceeds the amount paid for, the processor then turns off the valve and the process is repeated (Kumwenda, 2006).

Prepaid water meters were designed with the primary aim of cost recovery. They are stated to have emerged due to the introduction of the privatization philosophy (Kumwenda 2006).



2.3.8.3 Simple digital meters

A simple digital meter is merely an electronic version of the traditional mechanical meter. However, instead of through a mechanical wheel it records the water used by means of a sensor. These meters are often used for simple time-of-day metering.

A meter of this type may be read visually like the mechanical meter, or by using a port mounted to the front. It must be read by a meter reader, just as the mechanical meters. There is no wireless receiver or transmitter inside.

Most models have an infrared communication port on the front which is used to read the meter and sometimes program it. The meter reader uses a wand to collect data either by walking or drive by.

2.4 Benefits and Drawbacks of each metering scheme s

2.4.1 Conventional meters

The following are the benefits of conventional meters:

- Compared to advanced meters, conventional meters have a low implementation cost
- Infrastructure is already established and functional (Blom, Cox & Raczka, 2010).

The following are the drawbacks of conventional meters:

- Data collection cannot be taken on a shorter interval and requires staff to manually read the meters
- Minimal information is obtained
- No leakage detection capabilities
- Billing and meter reading cost can be higher as compared to advanced meter systems (Blom, Cox & Raczka, 2010).

2.4.2 Advanced meters

The benefits of advanced meters are experienced by both utilities and consumers. As utilities are service providers and consumers are the end users, the direct benefits experienced by both parties have an indirect benefit on the users. Some benefits have a direct impact on both parties. This report, however, will look at the individual benefits to the utilities and the consumers respectively.



The following are the benefits of utilities using advanced meters:

- Meters can be used to monitor end water uses and as such are useful water demand management tools. (Beal, Stewart & Fielding, 2013)
- Meters have a leak detection capability and users and utilities can be alerted to leaks occurring (Blom, Cox & Raczka, 2010)
- Data acquired from advanced meters can be more personalized. Users are more alert of their consumption and can make amendments (Blom, Cox & Raczka, 2010).

The following are the drawbacks of using advanced meters:

- The implementation of advanced meters is costly (Blom, Cox & Raczka, 2010).
- Due to ability transfer of information to utilities and possibly consumers, users fear that their personal information is not secure (Giurco, White & Stewart, 2010).

2.5 Evaluation Framework

2.5.1 Introduction

One of the planned outcomes for this research project was the evaluation of case studies on the performance of implemented advanced metering systems. To achieve this, an evaluation framework had to be developed that would analyse existing case studies, from literature, on four performance criteria, i.e. technical, economic, social, and environmental.

2.5.2 Framework overview

Jabareen (2009) maintains that in our present time, most social phenomena are complex as they are linked to multiple bodies of knowledge that belong to different disciplines. He further states that in order to get a better understanding of such phenomena, a multi-disciplinary approach is required. A qualitative tool that employs this multi-disciplinary approach is known as a framework.

The literature consulted gives numerous definitions of a framework. Paim and Flexa (2011) present a framework as a conceptual structure that enables different objects to be framed and treated homogeneously. They further state that a framework can be defined as a set of concepts used to solve a problem in a specific domain.

Similarly, upon stating the purpose of a framework, Jabareen (2009) defines a framework as a network or “a plane” of interlinked concepts that together provide a comprehensive



understanding of a phenomenon or phenomena. Furthermore, the framework is not simply a collection of concepts but rather a construct in which each concept plays an integral role. In agreement with Jabareen, Miles and Huberman (1994) state that a framework lays out the key factors, constructs or variables and presumes relationships among them.

From these definitions, one of the resulting considerations is the fundamental importance of concepts or indicators to the formulation and operation of a framework. According to Nardo et al. (2008), an indicator is a qualitative or quantitative measure derived from a series of observed facts that can reveal positions in a given area. Mainguet and Baye (2006) concur with this in stating that indicators are tools meant to describe the quality, the effectiveness, the equity, or the trends of a particular aspect of a system.

Indicators play a key role in assessing benchmarks, monitoring systems and providing warning lights that call for an intervention (Mainguet & Baye, 2006). To achieve this, indicators need to consist of qualitative and quantitative data over widely differing ranges (Carden & Armitage, 2013). As a result, good and effective indicators should be robust, coherent with other indicators, feasible, accessible to a large audience, precise, measurable and timely (Mainguet & Baye, 2006; Gage & Dunn, 2009; UN-Women, 2011). The resulting framework of indicators can aid to anticipate and display the possible relationships between variables, and how the variables work together to produce a global effect to a system (Shavelson, McDonnel & Oakes, 2003).

Numerous such frameworks were considered for this research. They are outlined in the following section.

2.5.3 Types of evaluation frameworks

2.5.3.1 Sustainability framework

The inception of the sustainability framework, which originated in Sydney, Australia, arose from the need to develop a methodology for evaluating the overall sustainability of urban water systems (Lundie et al., 2005). This methodology was being used to assist the Australian urban water industry to achieve more sustainable use of scarce water resources. Through this methodology, the industry would evaluate the sustainability of the various supply and demand options while considering the economic, environmental, human health, technical and social factors (Lundie et al., 2005).

The development of this methodology was further spurred on by the Intergovernmental Agreement for a National Water Initiative in Australia which identified the need to create water-sensitive cities. This initiative especially called for national guidelines for evaluating options for

water-sensitive urban developments in both new urban sub-divisions and high-rise buildings (Lundie et al., 2005).

In the development of the framework, stakeholder involvement and iterative procedures of activities were identified as vital and critical attributes were needed to establish more sustainable options for the water industry. As such, the proposed layout of the framework consisted of six phases as is illustrated by Figure 2-21. Each phase consisted of two components, the first addressing the procedure of how to carry out each phase and the second component focusing on the need for stakeholder participation. Figure 2-21 displays the final proposed layout, illustrating the different phases and the procedure of each phase.

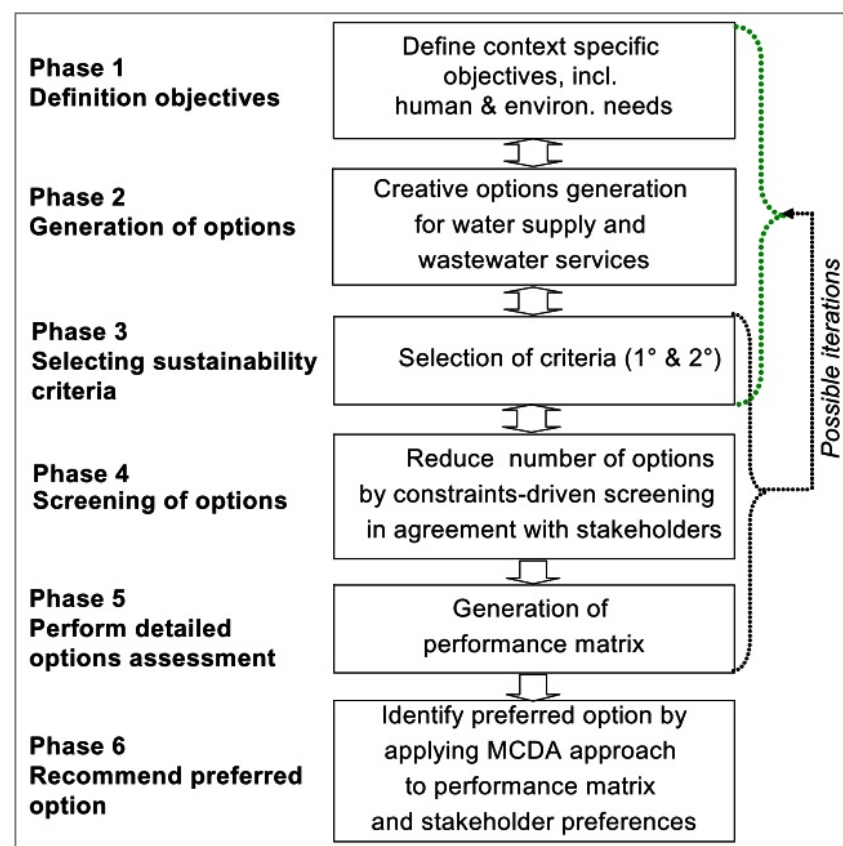


Figure 2-21: Layout and phases of a Sustainability Framework

Sustainability framework can be made flexible to allow its application for systems varying in the following:

- Scale of participation necessary
- Financial requirements
- System boundaries of a project



- Asset life-time (Lundie et al., 2005)

However, despite its flexibility in the above stated areas, the sustainable evaluation frameworks procedure and protocols that govern the evaluation process are rigid.

2.5.3.2 Composite Indicators Framework

A Composite Indicator Framework, also known as a Composite Indicator, is an aggregate of all dimensions, objectives, individual indicators and variables used (Nardo et al. 2005 and 2008). It is formed when individual indicators are combined into a single index on the basis of an underlying model of the multi-dimensional concept that is being measured (OECD, 2004). Through the Composite Indicator Framework, multi-dimensional concepts (such as competitiveness or e-trade) which cannot be captured by a single indicator can be measured (OECD, 2004).

Composite Indicators (CI) are often used wherever a plurality of variables are needed for evaluation and comparative purposes (Munda & Nardo, 2005; Nardo et al., 2008). Composite Indicators have been widely utilized to compare the performances of countries in fields such as the environment and technical development, and they are recognized to be useful tools in policy analysis and public communication. This is due to the simplistic manner in which Composite Indicators outputs can be compared and hence interpreted as compared to finding trends with separate indicators (Nardo et al. 2005 and 2008).

However, Composite Indicators can be misleading if poorly constructed. Therefore, to avoid misinterpretation, both a well-developed framework and good quality data are vital (Nardo et al., 2005, 2008). To construct an adequate Composite Indicator Framework, a sequence of steps needs to be adhered to as is illustrated in Table 2-1.

Table 2-1: Description of the different steps of the construction of Composite Framework (adapted from Nardo et al. 2005 and 2008)

	Design Step	Description
1	Theoretical framework	In the first phase of constructing a Composite Indicator, a theoretical framework must be developed. The theoretical framework is developed to provide the basis for the selection and combination of single indicators. With regards to advance metering, the selected indicators will be gauging the economic vitality, environmental friendliness, social acceptance, and technical practicability of both conventional and advanced meters.
2	Variable selection	



		In this phase, indicators are selected based on their analytical soundness, measurability and relevance to the phenomenon being measured and relationship to each other. For this project, the clarification of how the economic vitality, environmental friendliness, social acceptance, and technical practicability performance will be accessed should be well elaborated and understood in order to collect the required data.
3	Imputation of missing data	In this phase, careful consideration is given to various approaches that can be taken for imputing missing values. Extreme values should be carefully examined as they unintended benchmarks.
4	Multivariate analysis	In this phase, an investigative analysis is implemented to investigate the overall structure of the indicators, assess the suitability of the data set, and explain the methodological choices, e.g. weighting and aggregation.
5	Normalisation	In this phase, indicators are normalised to render them comparable. Attention needs to be paid to extreme values as they may influence subsequent steps in the process of building a composite indicator. Skewed data should also be identified and accounted for.
6	Weighting and aggregation	In this phase, indicators are aggregated and weighted according to the underlying theoretical framework. Correlation and compensability issues among indicators need to be considered and either be corrected for or treated as features of the phenomenon that need to be retained in the analysis.
7	Robustness and sensitivity	In this phase, an analysis needs to be undertaken to assess the robustness of the composite indicator in terms of, for example, the mechanism for including or excluding single indicators, the normalisation scheme, the imputation of missing data, the choice of weights and the aggregation method.
8	Presentation and visualisation	In this phase, composite indicators are visualised or presented in a number of different ways which can influence their interpretation.

2.5.3.3 Results Framework

The success or failure of an implemented project is difficult to gauge unless the expected results are clearly articulated. Based on this premise, results-based management is utilized as a key tool to monitor development effectiveness (World Bank 2012).

A Results Framework is an example of a tool that can be utilized for results-based management. A Results Framework is an explicit articulation (graphic display, summary, or matrix) of the different levels of results expected from a particular project (World Bank 2012). The Results Framework illustrates the direct relationships between the intermediate results of activities all the way to the overall objectives and goals. It also outlines how each intermediate results/outputs and outcomes relate to and facilitate the achievement of each objective as well as how objectives relate to each other and to the main goal (UN-Women 2011). Figure 2-22 displays an example of an implemented Results Framework.

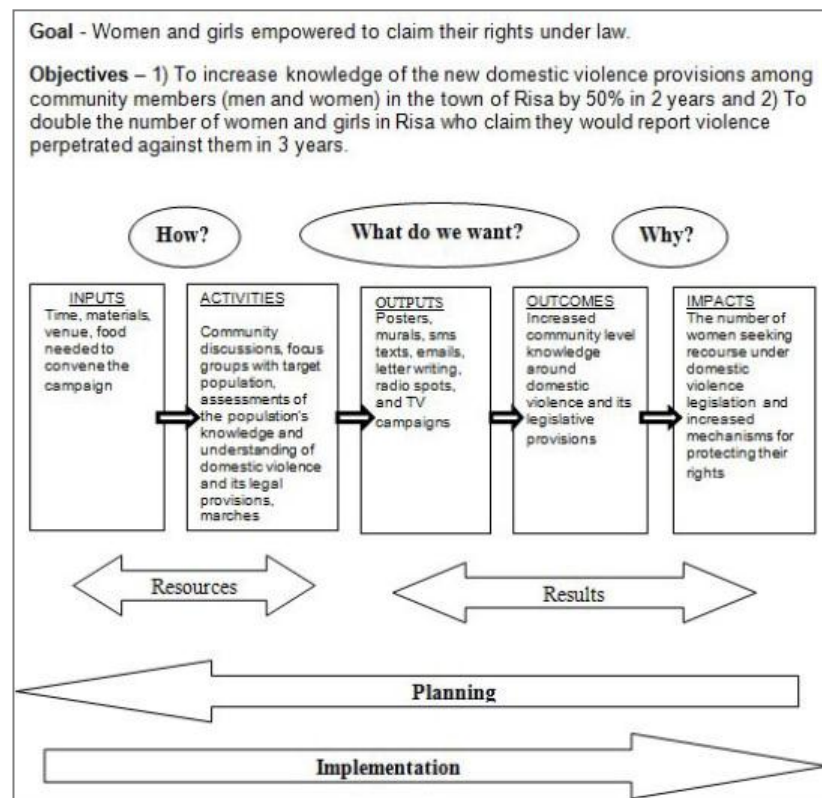


Figure 2-22: An example of an implemented Results Framework for an awareness-raising campaign around domestic violence legislation (adapted from UN-Women 2011)

2.5.3.4 Logical Framework

The Logical Framework, also known as Logical Model or Project Planning Matrix, was developed for the United States Agency for International Development (USAID) as a tool to aid



in the conceptualization and strengthening of a project design, the implementation and evaluation and the analysis of the assumptions behind it (Gra, 1990; Bakewell & Garbutt, 2005; UN-Women, 2011). Since the development of the Logical Framework, it has been adopted, through various revisions, by a large number of bilateral and international development organizations. The Logical Framework has proven extremely valuable for project design, implementation, monitoring, and evaluation (Bakewell & Garbutt, 2005).

The Logical Framework provides a linear, “logical” interpretation of the relationship between inputs, activities, outputs, outcomes and impacts with respect to objectives and goals. It outlines the specific inputs needed to carry out the activities or processes to produce specific outputs which will result in specific outcomes and impacts. Logical Frameworks form the basis for monitoring and evaluation activities for all stages of a system (UN-Women, 2011).

Logical Frameworks are valuable tools for:

- Programme Planning and Development: the Logical Framework structure aids with the programme strategy, i.e. to help clarify what stage the programme is at and where it should be.
- Programme Management: through "connecting the dots" between resources, activities, and outcomes, a logical model can be used as the basis for developing a more detailed management plan. Using data collection and an evaluation plan, the Logical Framework helps to track and monitor operations to better manage results. It can serve as the foundation for creating budgets and work plans.
- Communication: a well-built Logical Framework is a powerful communications tool. It can show stakeholders at a glance what a programme is doing (activities) and what it is achieving (outcomes), emphasizing the link between the two.

Logical Frameworks are presented as diagrams connecting programme inputs to processes, outputs, outcome and impact as they relate to a specific problem or situation. A Logical Framework shows what resources the programme will need to accomplish its goals, what the programme will do, and what it hopes to achieve, emphasizing links between these aspects. Figure 2-23 illustrates the typical format of the Logical Framework.



Narrative summary	Objectively verifiable indicators	Means of verification	Assumptions
<i>Goal – the overall aim to which the project is expected to contribute</i>	Measures (direct or indirect) to show the project's contribution to the goal	Sources of information and methods used to show fulfillment of goal	Important events, conditions or decisions beyond the project's control necessary for maintaining the progress towards the goal
<i>Outcomes (or objectives) – the new situation which the projects is aiming to bring about</i>	Measures (direct or indirect) to show what progress is being made towards reaching the objectives	Sources of information and methods used to show progress against objectives	Important events, conditions or decisions beyond the project's control, which are necessary if achieving the objectives is going to contribute towards the overall goal
<i>Outputs – the results which should be within the control of the project management</i>	Measures (direct or indirect) to show if project outputs are being delivered	Sources of information and methods used to show delivery of outputs	Important events, conditions or decisions beyond the project's control, which are necessary if producing the outputs is going to help achieve the objectives
<i>Activities – the things which have to be done by the project to produce the outputs</i>	Measures (direct or indirect) to show if project outputs are being delivered	Sources of information and methods used to show that activities have been completed	Important events, conditions or decisions beyond the project's control, which are necessary if completing activities will produce the required outputs
<i>Inputs</i>	Resources – type and level of resources needed for the project Finance – overall budget Time – Planned start and end date		

Figure 2-23: A typical layout of a Logical Framework



3 CASE STUDIES

3.1 Introduction

Case studies are recorded reports on projects and schemes that have been previously implemented to solve a certain problem or improve on a current situation. Case studies give a summarized account of the situation prior to the project, the reason for implementing the project, the implementation process as well as the output of the project.

This chapter discusses case studies found in the consulted literature. They serve to illustrate scenarios in which advanced metering was the preferred solution and illustrate the objectives these meters were to met, These case studies were sourced from manufacturing companies, projects (both completed and on-going) and other sources.

3.2 Burbank Water and Power, USA

3.2.1 Project background

Burbank is situated in California, USA, and is known as a pioneering media and entertainment oriented city that requires 21st century infrastructure and technology. Burbank is a high-tech city and home to three major movie production studios. As such, the city needs consistent and high quality water and electricity supply.

Since 1913, Burbank Water and Power (BWP) has been entrusted to supply water and electricity to its residences and currently supplies the utilities to 45,000 residences and 6000 businesses. In 2008, the community-owned utility embarked on a comprehensive Advanced Grid initiative. This initiative entailed that the grid's foundation, a meter data management system (MDMS), was established along with a robust meter to cash capabilities. Full details of this project can be obtained from the Siemens website (Fletcher, 2013).

3.2.2 Drivers for the implementation

The following are the drivers that led to the initiation and implementation of this initiative:

- **Increase efficiency:** Since Burbank's energy demand was increasing by 1.5% per year, there was a need for more accurate and timely meter data to better manage the resources to meet the increase in demand (Fletcher, 2013).
- **Improve reliability:** Power availability is a concern in California when temperatures are particularly high. Monitoring and controlling demand to reduce



peak load would help maintain power to customers and hasten communication and recovery should an interruption occur (Fletcher, 2013).

- **Reduce losses:** California is known to experience a water crisis due to the drought conditions and the judicial decisions. This has required the BWP to be more proactive in monitoring and preventing unaccounted water losses due to leaks and other factors (Fletcher, 2013).
- **Foster conservation:** Integrating advanced meter data with an MDMS and a billing system would empower BWP's customers to monitor their energy and water usage patterns in order to reduce or reschedule consumption and lower their utility bills (Fletcher, 2013).
- **Promote renewable energy:** In order to increase the use of renewable energy sources such as solar, wind and geothermal power, and integrate the customers' own electricity generation and storage into the energy grid, different infrastructure and control systems were required (Fletcher, 2013).
- **Ensure competitiveness:** BWP needed to keep up with private utility technology and process trends in order to remain competitive, should California again embark on deregulation (Fletcher, 2013).

3.2.3 Implementation of the project

Prior to the implementation of the project, the biggest concern was the security of private information that would be transmitted between the consumers and the utility. To solve this concern, the MDMS needed to be tightly secured so that both the utility's and customers' privacy would be preserved and protected. The MDMS needed to be easily configured to BWP's business rules without assistance from a programmer. It had to be scalable to accommodate a growing user base, more intelligent and diverse technologies, and BWP's evolving vision, without sacrificing service speed or efficiency. It also required an open architecture with the ability to support digital advanced meters from multiple manufacturers to allow flexibility in the Advanced Grid infrastructure (Fletcher, 2013).

The first step in the implementation phase was the meter-to-cash implementation. This was seen as a crucial stage as it consisted of integration between the AMI and MDMS as well as the BWP's existing customer information system (CIS).

The AMI, including advanced electric and water meters and wireless mesh network communications, would allow for bi-directional communications with the meters at more timely intervals, scheduled or on demand. The meter reads would be validated, estimated and



edited (VEE) within the MDMS to ensure their accuracy and completeness before conversion into billing determinants. Because the billing data would be more precise, BWP would be able to provide faster and more efficient customer service.

This implementation would also lay the foundation for additional meters and increasingly sophisticated Advanced Grid and MDMS capabilities such as remote connect and reconnect, demand response, thermal energy storage, voltage diagnostics, time-of-use pricing and a customer portal.

Also targeted were integrations with BWP's outage management system and a future energy demand management system, and possible electric vehicle integration.

3.2.4 Product selection for the project

BWP utility conducted an extensive search before choosing its Advanced Grid software solution provider. They used their business, technical, and security requirements as the criteria for choosing the best Advanced Grid provider. The eMeter EnergyIP was found to be the best solution for the project. This product was developed by a joint venture between Siemens Energy and eMeter Corporation. It is a reputable product that not only obtains meter readings and acts as data repository, but it is also a scalable Advanced Grid data platform designed to support future utility needs.

3.2.5 Results of the project

Once the MDMS had been implemented, several benefits and outcomes were realized, particularly for customers with an AMI meter installed. As the meter rollout continues, and additional MDMS capabilities and integrations are enabled, the positive effects will become more pervasive and quantifiable. These effects are as follows:

- Customers receiving near real-time data on energy usage from AMI meters are now able to make better consumption and conservation decisions.
- BWP will provide significantly enhanced service to its AMI utility customers due to improved billing accuracy and faster, more efficient customer response.
- Access to granular interval data will ultimately allow for fewer billing exceptions and customer billing queries.
- With the gathering of granular data, BWP can proactively gauge each issue as the problem arises.
- Business rules, such as VEE, may be configured as BWP's business needs evolve, without requiring a programmer's involvement.



- Interval data will reveal more timely evidence of leaks or other unaccountable water losses.
- Any water meters recording data but not being billed will be identified as a result of the AMI replacement, allowing accounts to be properly established.
- Field force personnel dedicated to manual meter reads may be shifted to other tasks as the AMI rollout progresses.

3.3 Sustainable Dubuque Initiative in Iowa, USA

3.3.1 Project background

In 2010, the City of Dubuque, Iowa, with a population of 60,000, started a water conservation initiative known as Sustainable Dubuque Initiative. The aim of the initiative was to make the city a “viable, liveable and equitable community that embraces economic prosperity, social-cultural vibrancy, and environmental integrity to create a sustainable legacy for generations to come” (Nicholson et al., 2012). The initial act undertaken under the initiative was to replace all existing water meters with advanced meters for 23,000 homes and small businesses (Nicholson et al., 2012).

3.3.2 Drivers for the implementation

The aim and drivers of the initiative were as follows:

- **Establish consumption baseline:** The city wanted to establish a new baseline for water consumption in which it would use advanced meters to monitor, compare and contrast future consumption.
- **Increase awareness and water conservation:** Through the use of advanced meters, the city hoped to educate the public about water conservation, provide more regular data on their consumption pattern and reduce overall water usage (Nicholson et al., 2012).

3.3.3 Implementation of the project

A pilot program provided over 300 Dubuque households with information, analysis, insights, and social computing around their water consumption to test the hypothesis that informed and incentivised citizens would be able to conserve water more efficiently (Nicholson et al., 2012).



3.3.4 Results of the project

The pilot program was in operation over three months, and results confirmed this hypothesis. This led Dubuque to expand the pilot to an additional 4,000 Dubuque households. Water savings were measured by comparing and weighing the consumption of the 151 pilot households with another 152 control group households with identical advanced meters but without access to the analysis and insights provided by the water pilot study for the nine-week duration (Nicholson et al., 2012).

The customers in the pilot conserved an estimated total of about 337 kilolitres of water over a nine-week period, with an average savings of 6.6% per household. If extrapolated to a full year, this would be a savings of 1948 kilolitres in total, or 12.9 kilolitres per household annually. Assuming that the 151 households were a fair sample of the city of Dubuque, the aggregate annual water savings across 23,000 households with advanced meters in the city would be estimated to about 245,841 kilolitres. This would translate into an aggregate water bill saving of \$190,936 a year in total. Technology vendors involved in the pilot included IBM, the Neptune Technology Group, and ESRI (Nicholson et al., 2012).

3.4 Pinetop Waters in Arizona, USA

3.4.1 Project background

Pinetop, situated in Arizona, USA, is a town known for snowy winters and lakeside retreats during the summer. During winter, the town's lakes and rivers are frozen with most of the residents indoors and some travelling to the Arizona desert until summer. Pinetop Water supplies and monitors the region's water supply. During winter, Pinetop Water faced vast difficulties in monitoring and managing the water supply.

Pinetop has five water sites, including wells and tanks that had to be monitored daily. This monitoring required staff time, transportation and constant attention. In winter, Pinetop Water has a treacherous time of navigating icy roads, buried meters, shifting well and tank levels with a staff of only five people (Sensus, 2013a).

Manual meter reads were time-consuming for water utilities and could also be costly, subject to human error, environmentally harmful due to carbon emissions and dangerous for employees, especially in inclement weather. Pinetop Water was also faced with the difficulty of trying to provide the town's citizens with a reliable supply of water all year round as well as with a means of detecting leaks early.

Pinetop Water therefore sought an automation technology solution for these sites. Automation equated to fewer overtime hours, less travel and carbon emissions and ensuring



constant water supply to customers. Prior to the automation technology, a Pinetop employee visited water sites seven days a week to check water levels, turn wells on or off and make sure that there are no power outages. The need for an automation system led Pinetop Water to liaise with Sensus to provide a solution to the utility's problems.

A project was initiated to install advanced meters that would allow the utility to remotely manage and monitor the water tanks and wells, using automation technology.

3.4.2 Drivers for the implementation

The drivers for the project were as follows:

- **Increase security:** With the aid of advanced meters, the employees of Pinetop Waters could obtain the readings from their offices. This would reduce their exposure to dangerous weather.
- **Reliable water:** With the automation technology, the utility would be able to remotely manage and monitor the water tanks. This would result in better control and more reliable water supply to the residences.
- **Reduce loss:** As the advanced meters could aid the utility detect water leaks, the amount of water lost could be significantly reduced.
- **Reduce cost:** With the ability to read and monitor the water consumption remotely, Pinetop Water would be able to save on the costs incurred from fuel and machinery used to read meters and investigate water levels.

3.4.3 Implementation of the project

Pinetop Water selected the advanced water network solution from Sensus. This system relies on the open standards based, multi-application FlexNet™ communication network and includes automation for monitoring well and tank levels. Pinetop also planned to change out or retro-fit their entire meter fleet with Sensus advanced points.

Automation would enable the water utility to have constant access to water from the safety and comfort of their office using a computer, tablet or even advanced phone. Water tanks were key system components, holding water pumped from the well prior to customer use. Sensus automation technology turns wells on or off based on water levels in the tanks and sends alerts when the water levels become too low. Alerts about power outages are also sent.

Pinetop also relied on Sensus' data centres for its meter data management. The amount of data an advanced water network provides is useful, but sometimes overwhelming for small water utilities like Pinetop. By pairing their advanced water network with Sensus network



hosting services, Pinetop Water would be able to simplify billing and account management, network management functions and data warehousing all through one system. This solution also included the support of Sensus engineers monitoring Pinetop's communication base stations and meters around the clock to identify issues and rapidly deploy solutions.

3.4.4 Results of the project

Pinetop Water is no longer susceptible to the harsh winter conditions. The utility is now able to read the meters from their offices and complete the system maintenance that would often be postponed due to the weather. There is no lag time in the customers billing and leaks are easily detected.

The implementation of the advanced meter system has meant a reduction in cost for Pinetop Water due to man hours saved. Wells and tank levels are better controlled as manual monitoring often led to overflow which resulted in wasted water.

3.5 The drought in California, USA

3.5.1 Project background

California is currently undergoing a severe drought that began in 2012 as is illustrated by Figure 3-1. According to the California-Nevada Climate Application Program (CNAP, 2014), in 2014 the drought saw California record its lowest rainfall since 1977. The registered rainfall further decreased in 2015. Figure 3-2 shows the decline in rainfall and increase in temperature during the drought.

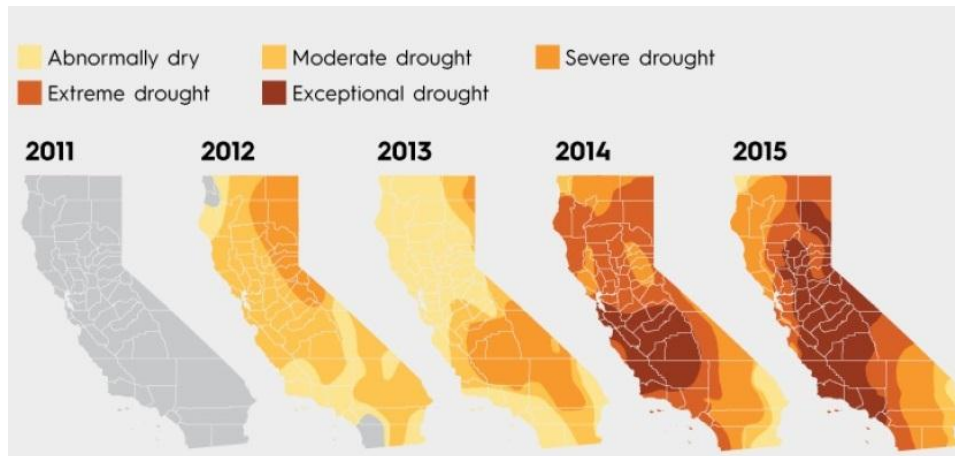


Figure 3-1: Demonstration of the drought progression in the state of California from 2012 to 2015 (French, 2015)

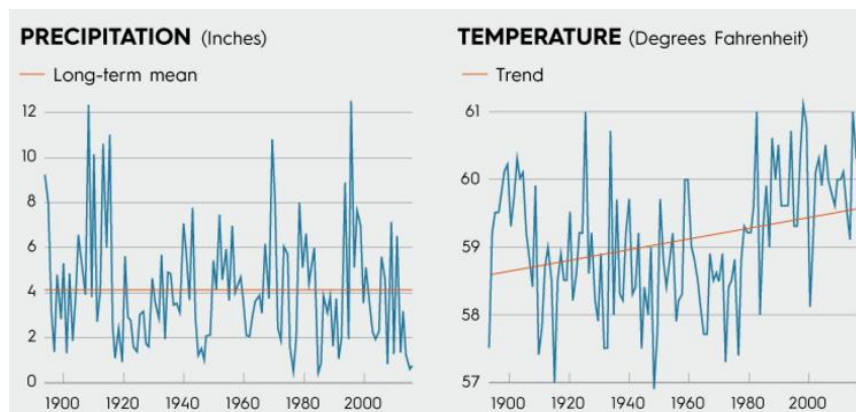


Figure 3-2: California's Rainfall and Temperature profile (French, 2015)

Much of California's water supply relies on the precipitation in the Sierra Nevada Mountains. California's frequent rainy period occurs during the winter season. The rain that falls in the Sierra Nevada Mountains becomes snow pack and acts as the water storage for the state (CNAP, 2014). During summer, the snow pack melts and flows into the Sacramento San Joaquin Delta. The Sierra Nevada snow pack provides the state with a third of its water supply; however, due to the drought, the snow pack now only provides 1/20 of its annual average (French, 2015). Figure 3-3 below illustrates the decrease in the amount of the snow pack and the amount of water provided by the snow pack.

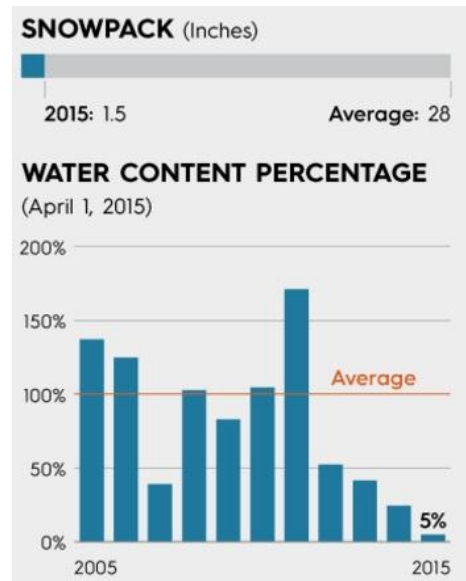


Figure 3-3: Amount and water content percentage of the Sierra Nevada snow pack in 2015 (French, 2015)

As a result of the limited water supply, the state of California declared a water crisis and pursued to outline mitigation procedures to be implemented; one of them was the water restriction enforced by the state governor, Jerry Brown. These restrictions required residents to reduce monthly consumption by 25% through reduction and omission of non-vital water use such as watering the lawn (Brown et al., 2015). Failure to adhere to the water restrictions resulted in a penalty that would be as high as \$100. However, the water utilities and residents could not monitor the water consumption. Therefore, advanced water meters were implemented to aid in more efficient water consumption (Finley, 2015).

3.5.2 Drivers for the implementation

The drivers for this implementation were as follows:

- **Preservation of current water resources:** Due to the drought, California's water resources and reserves were very low.
- **Reduce water consumption:** Due to the water scarcity, the available water needed to be used sparingly. As per the mandatory water reduction, the state aimed to reduce water consumption and as such looked to advanced meters for aid in water management. It also helped residents monitor how much water they were consuming.
- **Reduce loss:** The state of affairs in California made it imperative that water leaks be detected. Advanced meters were deployed to significantly reduce water loss and reach the restriction goals.



3.5.3 Implementation of the project

To aid with the mandatory water restrictions, advanced water meter rollouts were conducted in most cities in California such as Long Beach, Redwood and San Francisco (Finley, 2015). San Francisco was the largest city in California to make the full switch to advanced water meters, with the technology now deployed in 96% of the residences. The city wanted not only more accurate but also more frequent reads as well as the ability to share detailed data with consumers and identify and stop leaks faster. It chose a communications system from Aclara; most of the meters are from Elster/AMCO (Tweed, 2015).

Despite the restriction mandate enforced on the state, San Francisco may only have to reduce water use by an additional 10%. The city averages about 45 gallons per capita per day as compared to 69 in Los Angeles and 81 in Sacramento. For those municipalities that have been more lenient with water restrictions as the drought has persisted, the mandatory cuts could rise above 30%.

Now, the data is collected every few hours from the meter and San Francisco can alert a customer after abnormal usage levels that last three days. For the time being, the city places a phone call and sends out a postcard to tell the water customer about the potential leak.

3.5.4 Results of the project

Advanced water meters in Long Beach aided in detecting water losses. The director of the Long Beach Water Department, Tai Tseng, was documented as stating that one consumer was able to cut their water bill by 98% due to leakage detection (Castle, 2016).

3.6 Anglian Water in Colchester, UK

3.6.1 Project background

Colchester in the east of the UK, is projected to have a 34% increase in the number of households by 2033. This means that Colchester will be the fastest growing region in the UK. However, Colchester is also the driest region in the UK with only approximately 600 millimetres of annual rainfall.

Anglian Water is a UK water company that supplies and monitors the water consumption of its users. Currently, about 70% of its customers are metered with conventional meters; however Anglian Water aims that all water supplied to customers is metered. Through the use of conventional meters, it was shown that each household saved on average £100 per annum, hence reducing the water consumption between 5% and 15%.



However, Anglian Water aims to reduce the consumption even further by the use of advanced meters. This has resulted in a joint venture between Elster and Anglian Water to introduce advanced water meters in Colchester (Anglian Water, 2014).

3.6.2 Drivers for the implementation

The following are the driving factors for the implementation of this transition:

- **Reduce losses:** Since Colchester has limited water resources and low annual rainfall, Anglian Water aimed to reduce the water wasted through leaks due to late detection.
- **Improved efficiency:** Anglian Water aimed to maximize water consumption due to the limited water resources available.
- **Increase savings:** An increase in efficiency would lead to an increase in savings as consumers and utilities reduce the expense of water loss.
- **Increase conservation:** With the ability of the consumer and the utility to receive more frequent consumption records, Anglian water aimed to increase consumer awareness of the need to better conserve their water supply.

3.6.3 Implementation of the project

As part of a large scale pilot test of advanced meter technology, Anglian Water began the transition from conventional meters to advanced meters by deploying about 8500 advanced meters to the most water stressed areas in Colchester. Paul Glass, the project manager for Anglian Water, stated that their biggest challenge was the limited water resources, so they maximized the number of meters installed to boost water savings. He also stated that Anglian Water incurred an additional expense of installing radio meters due to the size of the area.

Advanced meters with two-way radio communication technologies were to be implemented in the project. However, Anglian Water was concerned that the two-way technology would enhance the degradation of the battery within the meter. They then evaluated a range of options including a clip on a modular device, but these displayed an array of complexity with regards to installation and commission. There was also the fear that such options could be easily tampered with.

Elster proposed that Anglian Water use their V200 and V210 hybrid meters. These meters can support both one- and two-way radio communication and feature integrated AMR within the same device. As a purely two-way meter would shorten the lifespan of the battery, a one- and two-way meter allowed the user some flexibility (Anglian Water, 2014).



3.6.4 Results of the project

Elster and Anglian Water collaborated to closely monitor the pilot test in Colchester. The two parties each conducted their own programme of meter readings to verify the performance and then collated and analysed the data in detail. The results revealed that the quickest means of reading the meters was the drive-by method; however, the walk-by method is also an alternative. Stephen Spicily, sales manager of Elster, stated that the combination of reading methods provided an efficient way of reading the meters installed across a large area.

3.7 Shelburne in Ontario, Canada

3.7.1 Project background

Shelburne is a small, fast growing town in Ontario, Canada. Shelburne was founded in 1860 and has a population of 5850 residents based on the latest census (Statistics Canada, 2011; Sensus, 2013b). Shelburne is a fast-growing industrial area and a tourist destination due to its annual Canadian Championship Fiddling Contest. With the city of Toronto approximately 107 kilometres away, Shelburne is viewed as the ideal industrial region. Consequently, Shelburne projected an increase in the town's population and as such an increase in water demand (Sensus, 2013b).

However, Shelburne has no surface water and uses four wells as its main source of water. With the growth of the community and future increase projected, the town will require an ample supply of water. The need for sufficient water sources is even more apparent as the town's water usage had regularly reached its peak. The town's municipality also identified the need for a water infrastructure upgrade in order to enable the municipality to reduce the amount of water used per capita, demonstrate good stewardship through water conservation and provide fair, consistent billing to its growing customer base (Sensus, 2013b). Consequently, Shelburne municipality developed a plan to use advanced water meters to aid the municipality to meet, monitor and manage the city's increasing water demand.

3.7.2 Drivers of the implementation

The driving factors for the Shelburne project were as follows:

- **Better management of the water supply:** With the town expecting a fast increase in its population and limited water resources, Shelburne's municipality needed a system that would aid in monitoring and better management of the water supply.



- **Encourage water conversation:** With the advanced water metering system, Shelburne would be able to give its residents regular information on their consumption and encourage more water conservation.
- **Water leakage detection:** With regular data collected, the municipality would be able to detect leakages more quickly and minimize the loss of water.

3.7.3 Implementation of the project

With its goals and projected increase in population, Shelburne began the project by evaluating their requirements and expectations for the new metering system for the town. Prior to the project, Shelburne had not metered the majority of its residential customers and relied on a touch-read meter reading system for commercial customers. This required that meter readers would visit every meter and manually record the billing information. The commercial customers were billed on a bi-monthly basis which made it difficult to locate system leaks (Sensus, 2013b).

Shelburne assessed the different advanced metering systems, such as walk-by and drive-by, fixed-base and hybrid systems that could be implemented. The aim of the assessment was to choose a system that would aid the municipality to achieve its future goals and not cause an increase in overhead or burden to the IT department (Sensus, 2013b).

An end-to-end FlexNet Advanced Metering Infrastructure (AMI) designed by Sensus was chosen. This system is a point-to-multipoint system in which the single network has multiple channels served through a single communication highway (Sensus, 2013b). One communication base station was put in place with 2000 residential advanced meters installed. Several commercial advanced meters were also installed.

3.7.4 Results of the project

The implementation of an advanced water network improved the services to the residents of Shelburne. Since the installation of the communications network and advanced meters, Shelburne achieved a significant decrease in water consumption by providing their customers with insight into their individual water usage and water bills that reflect this usage. The result of reduced consumption was that Shelburne had more water available and prepared itself to meet the projected population growth.

The real-time data also aided in leak detection and the ability for Shelburne customer service representatives to quickly answer questions regarding water consumption. Due to this implementation, Shelburne was able to immediately detect leaks and alert customers, thereby



saving time and money that once was spent fielding customer inquiries about water usage (Sensus, 2013b).



4 EVALUATION FRAMEWORK

4.1 Introduction

As stated in the introduction chapter, the primary objective of this research is evaluate the feasibility of implementing an advanced metering systems in high income areas in South Africa. To achieve this goal, an evaluation framework was analyse the viability of implementing advanced metering technology based on four performance criteria, namely technical, economic, social, and environmental viability.

This chapter describes the evaluation framework for high income areas adopted for this research. It expounds on how the framework was developed, the rationale and assumptions behind the selection and estimation of input parameter ranges and the processes and calculations put in place to generate the framework results.

However, prior to accessing the performance of an advanced metering systems, the choice of water metering technology and the objective of its utilization has to be gauged. Therefore, the evaluation framework developed and utilized for this research project comprises of two phases:

- *Validation:* Validation is the process of assessing the metering technology chosen by the municipality to achieve their project objectives. In this phase the municipality's objectives are coupled with the capabilities and functionality offered by the selected water metering technologies. The main objectives of installing water metering technologies are outlined, stating the desired outcomes for each objective and the required capabilities and functionalities needed to achieve the task.
- *Evaluation:* Through the validation process, the metering technology options best suited to achieve the project objectives are narrowed down. Subsequently, the municipalities will need to perform an extensive evaluation to analyse which metering technology will best meet their objectives. This process will gauge the feasibility of each possible metering technology with regard to the above-mentioned four criteria, i.e. technical, economic, social and environmental feasibility.

4.2 Product validation

With the vast advances made in the development of metering technologies and multitude of products on the market, selecting the appropriate metering technology for a specific task is crucial. As each metering technology has a specific functionality and capability, a careful



selection of the metering technology has to be made in order to meet the desired project purposes and outcomes.

4.2.1 Minimum requirements

For water metering products to be implemented in South Africa, they must comply with the following standards set by the South African Bureau of Standards (SABS):

- ***SANS 1529-1 compliance:*** This is the standard for metrological properties of nominal diameters not exceeding 100mm.
- ***SANS 1529-9 compliance:*** This is the standard for the electronic indicators used in meters, electronic water meters and for electronic prepayment water measuring.
- ***STS compliance:*** This is the standard for all other electronic appliances or component that are retrofitted to water meters.

4.2.2 Defining objectives

The functionalities and capabilities of water metering technologies often appear to take precedence in the selection of a metering technology for implementation. However, it is imperative that the implementation of any water metering project follow a clear outline of the project's weighable objectives in order to predetermine the feasibility and success of the project.

Literature on past implementations and information on the functionalities and capabilities of advanced water metering technologies were used to identify the following as reasonable objectives for implementing such technologies:

- ***Cost recovery*** – increasing revenue from water sales in order to recover operational and capital costs
- ***Water demand management*** – encouraging users to use water more efficiently
- ***Improved network management*** – on-demand information on flow and demand patterns in the network
- ***Understanding consumer behaviour*** – monitoring trends in consumer behaviour.
- ***Consumer choice*** – providing consumers with alternative technologies to suit their needs



4.2.2.1 Cost recovery

Cost recovery is the process of raising financial resources with the primary purpose of recovering the cost incurred in maintaining and operating the water services as well as recovering the capital cost invested into the water services (Marah et al., 2003). Cost recovery is recognised as a crucial component in sustainable water service provision. It's essential for long term sustainability of the water service sector (Sedikila, 2008) . Cost recovery requires reaching an optimum blend of increased revenue for the water sector (known as the 3Ts; tariffs, taxes, and transfers) to match the costs incurred (OECD, 2009).

In countries, such as South Africa, municipalities' revenue is largely accounted from water sales. As such, accurate monitoring of the consumers' water consumption is imperative. However, lack of appropriate collection of income hinders cost recovery. In South Africa, this can be accounted to consumers unwillingness to pay, technological and data gathering redundancies and ineffective administration of billing and payment systems (Marah et al., 2003).

Consumer unwillingness to pay stems from the difficulty of getting the appropriate balance of sufficient tariff for revenue increase and affordability. Consumer unwillingness primarily occurs in low income areas however, consumers in high income areas have also been noted to avoid payment. Technological and data gathering redundancies have also been noted to occur. With conventional meters, data can only be collected once a month where as in some areas, estimates are made to the consumption level then verified after a significant period of time. Such was the case in Gauteng where consumers where told by the municipality to pay the difference between estimated consumption and actual consumption that back dates approximately 5.5 years (Gladwin, 2017).

As such, implementation of advanced meters can aid in improving the cost recovery for high income areas in South Africa. To achieve this objective, the following capabilities and functionalities of an advanced metering system should be noted:

- Regular consumption data recording, storing and transmitting
- A shut off or flow restriction valve to limit consumers that are unwilling to pay
- Monitor consumers accumulated monthly water consumption match with multi-step water tariff structure
- Tamper proof alarms

Though these factors are predominant in low income areas, there are occurrences in high income areas. Consumers in high income areas should be able to pay off their consumptions.



However, with advanced metering, consumption patterns can be better monitored and would assist in developing adequate tariff structures to reach a suitable cost recovery.

4.2.2.2 Water demand management

Water demand management (WDM) is briefly defined as the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource (Kayaga & Smout, 2007). However, DWAF, (2004a) expounds this further by defining it as “the adaption and implementation of a strategy by a water institute or consumer to influence the water demand and usage of water in order to meet the following objectives; economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability”.

WDM is vital in regions facing water scarcity and vast increase in water supply costs. As stated in the introduction, water scarcity is the unavailability of water when and where people need it (Seckler, Molden & Barker, 1999; Fry et al., 2006). South Africa is a region facing water scarcity. Increase in water demand due to factors such as population and urbanisation growth as well as economic and industrial growth result in a vastly increasing supply to meet the demand. This then rapidly increases the stress on the water resources. A continuation of this pattern results in the water resources inability to meet the ever-rising demand due to diminishing capacity. To prevent this, WDM strategies are often coupled with water conservation strategies. Water conservation (WC) is defined as “the minimization of loss or waste, care and protection of water resources and the efficient and effective use of water” (DWA, 2004).

For municipalities incurring high water supply costs, wise water consumption needs to be encouraged. Improved leakage management is also required to reduce amount of water lost. Water restrictions may also be enforced for luxurious activities such as watering the garden at certain terms during the day.

Water metering is vital to adequate WDM/WC approaches. For an advanced metering system to aid achieve this, the following capabilities and functionalities will be required:

- Regular consumption data recording, storing and transmitting
- Leakage detection
- Regular feedback to the consumer on water consumption
- Feedback on consumption exceed a set threshold



- Alert consumer of the impending rise in water tariff block due to increase in consumption
- Graphical generation and storage of regions consumption pattern and comparative capabilities

To fully realise these capabilities, adequate communication and data management structures will be needed as well as training for personnel needed to use these facilities

4.2.2.3 Improved network management

Water network management entails using sensors and measuring instruments such as meters, to collect to necessary data needed monitor, analyse, operate and maintain the water supply network. An efficient network management program results in more accurate account of water consumption patterns, better leakage detection, better preventive maintenance, accurate pressure and water quality monitoring, and prolonged infrastructure lifespan. An efficient network management program also aids in achieving the cost recovery targets as well as conduct adequate water demand management (Allen et al., 2016).

Metering is imperative to conduct network management. Data acquire from water meters aid in constructing a water balance for the region. Accurate and regular data collection can aid in reducing non-revenue which would, consequently, improve the water balance developed and hence the network management. As such, the capabilities required from an advanced metering system would be the following

- Real time data collection
- Data logging and transmission capabilities
- Remote data reading
- Remote configuration of the system
- Leakage detection
- Meter failure detection

4.2.2.4 Understanding consumer behaviour

Well comprehensive consumption data coupled with external data, such as regional activities, would better equip the municipalities to better understand consumer consumption behaviour and as such develop appropriate water and network management strategies. For example, better understanding of the regions water consumption patterns would allow the municipality to better regulate the amount of water supply at different time and peak zones. It would also aid in better



identifying possible leakage (Britton, Stewart & O'Halloran, 2013). A comprehensive understanding of the consumers consumption pattern would also aid in better managing regions facing water scarcity.

Advanced metering can be beneficial in achieving this goal. The metering system will be required to perform the following functionalities:

- Continuous data reading and storage
- Regular feedback to consumers on consumption patterns
- Time stamps on consumption data collected
- Tamper proof and alarm system

As this objective entail dealing directly with the consumer, improved customer care facilities should also be considered.

4.2.2.5 Consumer choice

The purpose of this objective is to give the consumer choice to intentionally select an advanced meter of their preference. This could be due the added benefits of an advanced meter or their pursuit of improved water conservation at their home etc.

This would be beneficial to the municipality as consumers would feel more in control of their water metering and consumption. This would lead the consumer to become more responsible for the meter maintenance, heir consumption and ability to pay (Britton, Stewart & O'Halloran, 2013).

To achieve this, the advance meter would need to have the following features:

- Regular data collection and storage
- Leakage detection capability
- Data transmission
- Tamper proof
- Regular consumption feedback



4.3 Evaluation phase

4.3.1 Introduction

After the validation process, the ranges of metering technologies that can be used in a metering implementation project are limited to those that meet the project objectives. Having narrowed down the array of possible solutions to select from, the municipality must then assess each metering product and system's performance and feasibility on the basis of the four performance criteria i.e. technical, environmental, economic and social. This is done through the evaluation phase of the framework.

For this research, composite indicator framework proved to be the ideal structure to utilize as compared to other possible framework structures highlighted in chapter 2.7.2. This is because composite indicator structure is a general structure that is not tailor made for a specific purpose. This meant that it could be adapted for this research allowing for any necessary indicators to be used.

The evaluation phase then acts as the mechanism of the chosen framework where by crucial performance parameters are selected to aid in assessing the different metering options selected based on the aforementioned criteria.

As this research tackles a relatively new field in the water sector, acquiring measured and practical data of the different parameters needed to assess the metering performances on the aforementioned criteria proved to be complex and difficult. As a result, the evaluation framework was designed to be simple yet effective with data acquired from existing literature in this field so that it can be utilized as an instrument to aid decision makers in discerning potential benefits, obstacles and possible solutions to the implementation of advanced metering.

To assess the performance of the advanced metering scheme, data was also acquired for the current conventional scheme and new conventional metering scheme. Current metering scheme would serve to gauge the changes that were brought about by implementing an advanced metering system. New conventional metering system however acted as a control. It served as a comparative and alternative option to the advanced metering system to access which new or proposed metering scheme would be more beneficial.

The conception and adaptive design evaluation framework was a joint venture with Malunga Masoabi, a colleague and researcher on the feasibility of advanced metering in low income areas. However, Malunga Masoabi was the main contributor to the final layout and design of this framework. The author of this research aided in identifying the parameters



needed for the framework, refining the framework upon initial developments and adapted the framework for high income areas. Though this thesis addresses high income areas in a South African context, significant volumes of data and research were taken from developed countries such as Australia, UK, USA, Maltese and France. These countries proved to have practical data of advanced meters implemented in high income areas and were therefore used as proxies where data for South African literature was lacking.

4.3.2 Input parameters

4.3.2.1 Introduction

This section discusses the input parameters required in the evaluation framework. Each parameter is described in detail and it is explained how the data for each parameter was acquired. To assess each of the above four criteria, qualitative and quantitative indicators or parameters were collected to aid in assessing the performance of each one of the selected metering solutions. For each quantitative parameter, the range of the typical, low and high value of that parameter is given. The evidence and rationale of each range was acquired from literature and surveys conducted on practitioners in the advanced metering field. The results of the surveys are illustrated in chapter 5.2. These quantitative ranges were necessary to conduct sensitivity analysis of the framework which is later elaborated in this thesis.

The surveys were conducted on practitioners in the water metering and distribution field from around the country at a Water Research Commission Workshop in November 2015. The surveys required that each participant fill in details of an advanced metering case study that they were involved in or have significant knowledge of. The practitioners surveyed comprised of water metering manufacturers, NGO personnel, water municipality' personnel, bulk water suppliers, consultants, contractors and observers. In total, there were 22 surveys collected with 10 surveys pertaining to high income areas and 5 surveys with adequate but incomplete data. As such data acquired from literature from developed countries and case studies abroad were used as the main source of data for the framework input data

The input parameters below are displayed in the same layout as they would appear in the evaluation framework. The parameters that affect high income areas are elaborated on and respective values are stated. Other parameters that do not affect high income areas are shaded in grey.

4.3.2.2 System parameters

System input parameters serve to provide the identity of a case study or system that is to be analysed. The parameters captured are summarized in Table 4-1.



Table 4-1: System input parameters

No	Parameter	Description
1.1	Analysis ID	A unique identifier for the analysis.
1.2	System name	A unique name for the analysis.
1.3	Suburb(s)	The suburb(s) the study is applied to.
1.4	City	The city in which the study is done.
1.5	Date	The date the analysis is done.



4.3.2.3 Global parameters

Global input parameters consist of the general data required throughout the duration of the analysis. Table 4-2 summarizes the global parameters and their respective ranges. These parameters are discussed in more detail in the rest of the section.

Table 4-2: Global input parameters

No	Parameter	Description	Typical	Low	High
2.1	Number of properties	The number of properties supplied with water in the study area.	1000	200	10 000
2.2	Water cost price (R/kl)	The cost of producing water to a water distribution system.	10	3	15
2.3	Applicable water tariff (R/kl)	The appropriate price a consumer is expected to pay for water services based on the amount of water consumed.	17	7	26
2.4	Meter under registration (%)	The percentage of water note registered by a customer's water meter due to intrinsic errors.	5%		
2.5	Billed unmetered tariff (R/kl)	The water tariff on a fixed supply of water for a given time period (usually a month). This does not apply to high income areas			

The ***number of properties*** (*parameter 2.1*) denotes the number of connections being supplied with water in the study area. In high income areas, in accordance with SANS 10252-1:2012, it is assumed that each property has its own connection point and there is no second party distribution (i.e. no backyard dwellers).

This parameter was determined through the size ranges of a district metered area (DMA) as DMAs are the pre-requisite for effective management of any distribution system (UN-Habitat, 2006). The typical size of a DMA is 2000 properties (Fantozzi, Calza & Lambert, 2009; Ibrahim, 2013). The minimum and maximum size of a DMA are typically from 500 and 5000 respectively, based on values noted by Herrera et al. (2010), UN-Habitat (2006) and Ibrahim (2013). However, case studies and the literature have shown DMAs can exceed the typical range (Lambert, Koelbl & Fuchs-Hanusch, 2014). Therefore, the chosen range for this parameter is between 200 and 10,000 properties as this encompasses most DMAs in high-income areas.

The ***water cost price*** is the production cost of water incurred by the municipality and includes the costs for raw water extraction and water treatment.

In South Africa, the water cost, in 2003, was averaging at R2.55 per kl with the price ranging from R1.36 per kl to R4.08 per kl as is illustrated in Figure 4-1 (Eberhard, 2003). Through the use of an online South African inflation calculator, the water cost was estimated to average at R5.13/kl with a range from R2.72 per kl to R8.21 per kl in 2016 value terms (Crause, 2013).

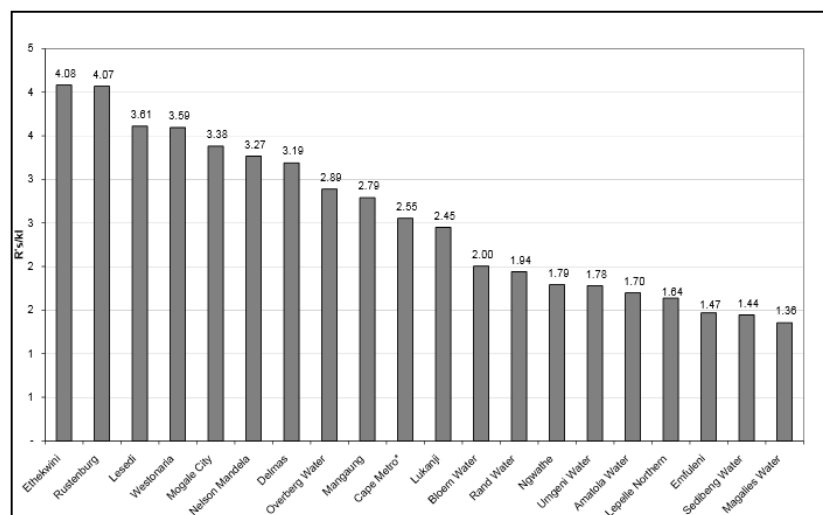


Figure 4-1: Graph water cost for different municipalities in 2003 (Eberhard, 2003)



In accordance with the Chamber of Trade and Industry (2007), in 2006 the typical water cost price was R4.06 /kl with a range from R2.09 /kl in Mpumalanga to R7.13 /kl in Kwazulu-Natal. Through the use of an online inflation calculator for South Africa, the typical cost was R7.63 /kl with a range from R3.93 per kl to R13.40 per kl in 2016 value terms (Crause, 2013). The projected values for 2016 by the Chamber of Trade and Industry (2007) prove to be significantly higher than the values projected by Eberhard (2003) for the same year. This may reflect that water inflation was significantly higher than consumer inflation.

From the surveys conducted, the water cost range for 2015 was found to be between R6 and R10 per kl. Through data acquired from De Sousa (2013) and Gibb (2015), the cost of water in 2016 in Cape Town and Durban were found to be R10 per kl and R5 per kl respectively. Based on the above data, the typical cost price assumed for this study was R8 /kl, with low and high values of R4 and R13 respectively.

In Australia, used here as a proxy for high-income countries, the production cost of water in New South Wales was AUD 0.75/kl in 2014 (Beal & Flynn 2014). Through the Australian inflation calculator, the 2016 cost is AUD 0.77 /kl (Reserve Bank of Australia, 2016), which is approximately R8.40/kl in South African currency. This falls well within the water cost range set for high-income areas.

The *applicable water tariff* is the price assigned to the water consumed by a customer based on the water structure utilised by the municipality. This parameter is critical as it measures the municipality's main source of income. The water tariff used is based on whether the endpoint is metered or not and on the type of tariff that is selected for the system. As this research focused on high-income areas, only tariff structures that apply to household connections as well as commercial and industrial area connections were considered.

South Africa has a total of 278 municipalities which comprise of 8 metropolitan (Category A), 44 district (Category B) and 226 local (Category C) municipalities. As directed by the Constitution, metropolitan or Category A municipalities provide services to cities or conurbations. Only water tariffs implemented in the metropolitan municipalities were used to determine the applicable water tariff range for this study.

In South Africa, increasing block tariffs are favoured for domestic metered consumption and non-domestic consumption (i.e. institutional, commercial and industrial). A block tariff comprises of different prices for water based on the amount of water consumed. However, in South Africa each municipality utilizes different water tariff structures.

Table 4-3 compares the water tariff structures for domestic consumption in the different South African metropolitan municipalities. Although all municipalities use the increasing



block tariff structure, each municipality charges different water prices for different quantities consumed.

Table 4-3: Water tariff structures for domestic and non-domestic consumption in different South African metropolitan municipalities

Quantity Consumed (kl/month)	Water Tariff for different municipalities (R/kl)								
	eThekwini	City of Johannesburg	City of Cape Town	City of Tshwane	Ekurhuleni				
Domestic Consumption									
0	14.27	0	0	7.73	0				
6		6.86	11.07	11.03	13.54				
9									
10	11.17					15.87	16.76	16.58	
10.5									
12									
15	16.86	22.92	23.57	20.71	20.63				
18									
20									
24	22.46	28.33	29.03	22.17	25.44				
25									
30									
35	34.63	38.3	38.3	23.73	18.82				
40									
42									
45	38.1	28.33	38.3	23.73	18.82				
50									
72									
> 72	38.1	28.33	38.3	23.73	18.82				
Non-domestic Consumption									
0						21.19	⁽¹⁾ 19.00 (26.25)	17.10	16.53
200									
2500									
10000	21.19	⁽¹⁾ 19.87 (27.47)	17.10	15.5	18.82				
100000									
>100000									

(1). This block illustrates the different water tariffs for non-domestic consumption in the City of Johannesburg: the prices in brackets () indicate the water tariffs for industry and commercial consumptions whereas the other price shows the water tariff for institutions.

In order to select an appropriate tariff bracket it is imperative to determine the consumption range for high-income areas in South Africa. Griffioen and van Zyl (2014)

addressed this matter in a study looking to propose a guideline for modelling water demand. This study indicated that the factors having the greatest impact on domestic consumption were household size, prolonged high temperatures, stand area and income. Of these, stand area was the predominant factor. Griffioen and van Zyl (2014) demonstrated the correlation between the Average Annual Daily Demand (AADD) and the stand areas. This is illustrated in Figures 4-2 and 4-3.

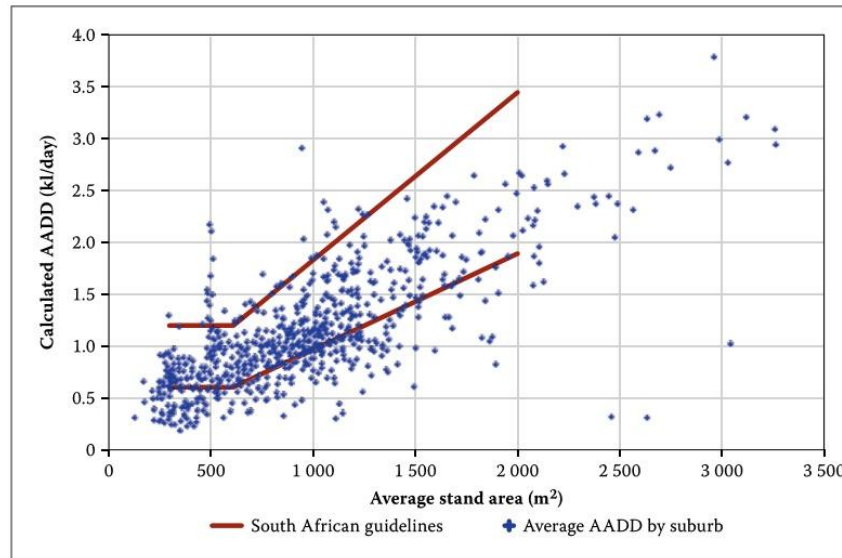


Figure 4-2: The average demand and stand area of 739 suburbs throughout South Africa and current South African design guidelines (Griffioen & van Zyl, 2014)

Figure 4-2 shows the consumption range of 739 suburbs against the upper and lower limit of the South African design guidelines. However, 4% were above and 38% were below the upper and lower limits respectively. As such Griffioen & van Zyl (2014) proposed new design envelope curves as is illustrated in Figure 4-3.

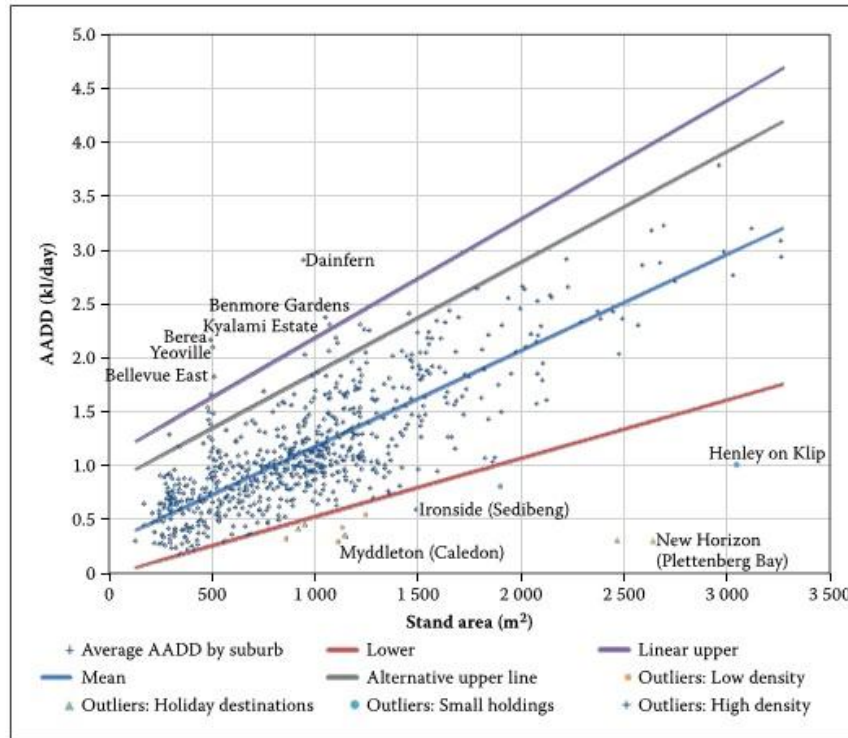


Figure 4-3: Proposed new design envelope curves for estimating the AADD of properties (Griffioen & van Zyl, 2014)

Figure 4-3 illustrates that most of the data samples were within the design curve. The data above the upper limit represents very high income consumers and data below the lower limit represents either coastal holiday homes or small, low density rural settlements.

Griffioen & van Zyl (2014) found that the median and average AADD were 1.0 kl per day and 1.1 kl per day respectively. Though the data samples used encompass both high and low income areas, majority of the data cluster around the median AADD. Therefore, the average AADD for high income areas was taken to be 1.0 kl per day. The minimum and maximum AADD were taken as 0.5 kl per day and 3.0 kl per day respectively.

Therefore, taking consumption over a period of a month (or 30 Days), the typical household consumption was selected to be 30 kl per property per month with the minimum and maximum consumption as 15 kl per property per month and 90 kl per property per month respectively.

With the determined consumption range, the applicable water tariff was determined through the weighted average method. This is illustrated by the sample calculations on the next page.



Weighted Average Sample Calculations

Quantity Consumed (kl/month)	eThekweni Municipality
0	14.27
6	
9	
10	16.86
10.5	
12	
15	
18	
20	
24	
25	
30	22.46
35	34.63
40	
42	
45	
50	38.1
72	
> 72	

$$\frac{\text{Typical Value}}{\text{Value}} = \frac{(R14.27 / \text{kl} \times 9 \text{ kl/month}) + (R16.86 / \text{kl} \times 16 \text{ kl/month}) + (R22.46 / \text{kl} \times 5 \text{ kl/month})}{30 \text{ kl/month}}$$

$$= R15.31 \text{ per kl}$$

$$\frac{\text{Minimum Value}}{\text{Value}} = \frac{(R14.27 / \text{kl} \times 9 \text{ kl/month}) + (R16.86 / \text{kl} \times 6 \text{ kl/month})}{15 \text{ kl/month}}$$

$$= R17.02 \text{ per kl}$$

$$\frac{\text{Maximum Value}}{\text{Value}} = \frac{(R14.27 / \text{kl} \times 9 \text{ kl/month}) + (R16.86 / \text{kl} \times 16 \text{ kl/month}) + (R22.46 / \text{kl} \times 5 \text{ kl/month}) + (R34.63 / \text{kl} \times 15 \text{ kl/month}) + (R38.10 / \text{kl} \times 45 \text{ kl/month})}{90 \text{ kl/month}}$$

$$= R30.49 \text{ per kl /kl}$$



The weighted average method uses an accumulative procedure where tariff brackets are multiplied by the respective quantities consumed on the bracket. The resulting products are summed up until the accumulative quantity consumed equates to the total quantity consumed of each critical parameter (i.e. typical, minimum and maximum). The summations of the products are then divided by the total quantity consumed of each critical parameter. Table 4-4 shows the weighted averages of the different municipalities and the overall average.

Table 4-4: Domestic and non-domestic consumption water tariff structures for different South African metropolitan municipalities

Critical Parameter	eThekweni	City of Johannesburg	City of Cape Town	City of Tshwane	Ekurhuleni	Average
Typical	17.02	16.93	14.54	13.84	12.35	14.94
Minimum	15.31	5.55	8.08	10.40	8.12	9.49
Maximum	30.49	21.68	28.02	19.51	20.28	24.00

Based on the results, the chosen typical water tariff was R15 per kl with a range from R9 per kl to R25 per kl.

Meter under registration (parameter 2.4) is the percentage given to the amount of water not registered by a customer's water meter due to intrinsic errors. This occurs when a water meter loses its efficiency due to meter aging, meter wear and tear, demand profile or demand type problems (Fantozzi et al. 2009).

According to Couvelis & van Zyl (2015), the typical percentage of flow not registered is 5% with a range from 2%-10%/. However, as this only affects current meters that have been in use, the range for this parameter becomes redundant for the sensitivity analysis. Therefore, only the 5% is taken into account and used in the evaluation framework.

The **billed unmetered tariff** (parameter 2.5) is flat rate price assigned for a fixed monthly consumption. In South Africa, this applies to second party distributors such as vendors and low income areas. As such, in this thesis, this parameter does not apply.

4.3.2.4 Current systems parameters

This section looks at the state of the existing systems before implementation of advanced water metering schemes. It's investigated in 3 sections; current consumption parameters, current payment levels, other current parameters.



Current consumption parameters

The *current consumption parameters* look at the property distribution of a study area based on their billing methods for water consumed. It's thusly consisting of 3 categories; *Billed metered consumption*, *Billed unmetered consumption* and *illegal or unbilled connections*.

For high income areas, billed unmetered consumptions is considered negligible as most billed unmetered consumptions relate to water vendors and other 2nd party water distributors. Therefore, Table 4-5 summarizes the current consumption parameters for high income areas and their respective ranges. These parameters are further elaborated in the rest of the section.

*Table 4-5: Current consumption parameters*

No	Parameter	Description	Typical (No. of properties)	Low (No. of properties)	High (No. of properties)
3.1	Billed metered consumption (%)	The percentage of the total properties in a study area who are billed due to their metered consumption	97%	90%	100%
	Billed metered unit consumption (kl/property/month)	The amount of water consumed per month by a metered property.	30	15	90
3.2	Billed unmetered consumption (%)	The percentage of the total properties in a study area who are billed due to at a fixed rate. This however does not apply to high income areas			
	Billed unmetered unit consumption (kl/property/month)	The amount of water consumed per month by a billed unmetered property. This parameter does not apply to high income areas			
3.3	Illegal or unbilled connections (%)	The percentage of the total properties in a study area that have illegal connection to the water network or are not billed for their consumption.	3%	0%	10%
	Illegal or unbilled unit consumption (kl/property/month)	The amount of water lost per month to illegal or unbilled consumptions	3	0	9
3.4	Total/average	This is the summation of the number of properties and the unit consumption of the different consumption group			
3.5	Billed metered consumption (meter under registration)	This is simply the billed metered consumption when considering metered registration. This is calculated by getting the product between the billed metered properties with the unit consumption registered by the metered (that is less the percentage of water not measured)			



Billed metered consumption (parameter 3.1) identifies which properties in a study area or pre-advanced metering implementation area are subject to the billed metered tariffs.

These are assumed to range from 95% of the total properties to 90% with the typical value as 100%. This is because residential zones comprise the highest number of properties in a metropolitan area

Illegal or unbilled consumption (parameter 3.3) identifies the connections illegally taped into the network or consumption that is not metered due to human intervention (e.g. surpassing the water meter).

This category is not synonymous with high income areas however based on our survey; a practitioner stated that these incidents can still be found in high income area. The assumed range for this parameter ranges from 0% to 10% with a typical value of 3%.

Unit consumption denotes the amount of water consumed per month per each consumption group. As billed unmetered does not apply to high income areas, the total water consumed will comprise of the amount of water consumed by billed metered properties and amount of water lost to illegal and unbilled properties.

These quantities were determined through the assumed percentages illustrated by Table 4-6

Table 4-6: Unit consumption for different consumption groups

Description	Quantity range		
	Typical	Low	High
Billed metered unit consumption	30	15	90
Illegal or unbilled unit consumption	3	0	9

With regards to billed metered unit consumption, the typical and range of unit consumption were determined through a study done by Griffioen & van Zyl (2014) as is illustrated by Figures 4-2 and 4-3. As previously discussed, this study was conducted for the purpose of proposing a guideline for modelling South Africa's water demand by suburb. The study found and displayed in Figure 4-2 and 4-3 that the median and average AADD were 1.0 kl per day and 1.1 kl per day respectively.

The median AADD of 1.0 kl per day was taken as the typical unit consumption with the low and high unit consumption taken as 0.5 kl per property per day and 3.0 kl per property per day respectively. Taking a month as a 30-day period, the typical billed metered unit



consumption equates to 30 kl per property per month with the low and high unit consumptions as 15 kl per property per month and 90 kl per property per month respectively.

However, concerning illegal connections, the unit consumption was assumed to be 10% of the billed unit consumption. It's assumed that in high income areas, occurrence of illegal connections is low.

Billed metered consumption (meter under registration) denotes the billed metered consumption of a study area when meter under-registration is considered.

Taking the meter under registration as 5% as stated in *parameter 2.4 (Meter under registration)*, this parameter was calculated by the equation below

$$\begin{aligned} \text{Billed metered consumption} &= \text{Billed metered consumption} \times (1 - 0.05) \\ (\text{meter under registration}) & \end{aligned} \quad \mathbf{4-1}$$

Current payment levels

This section looks at the proportion of each category's willingness to pay when billed for their consumption. As such only billed metered consumption applies in this section.

Table 4-7 summarizes the current payment levels for high income areas and their respective ranges. These parameters are further elaborated in the rest of the section.

*Table 4-7: Current payment levels parameters*

No	Parameter	Description	Typical	Low	High
3.6	Billed metered consumption payment rate (%)	The percentage of the billed metered properties willing to pay their bill	90%	85%	100%
3.7	Billed unmetered consumption payment rate (%)	The percentage of the billed unmetered properties willing to pay their bills. However, this parameter does not apply to high income areas			
3.8	Total	Summation of percentages.			



Billed metered consumption payment (parameter 3.6) represents the percentage of consumers paying for the water they have consumed. From literature, it is clear that numerous factors play a role in consumers' ability to pay for water. However, the most predominate one is poverty. DWAF (2004) states that poverty is the root challenge to the inability to pay for water services.

However, as this thesis is looking at the high-income areas, this was not expected to be a significant factor. As such it's assumed that a large proportion of high income area consumers would pay for their water services. However, according to 1 practitioner's survey, this isn't always the case. They state that from their experience, they have noted some high-income consumers by passing the meters so as to avoid to pay.

Therefore, though only one practitioner noted this, an allowance was given for a proportion of high income consumers not paying for their water consumption. As such, the range of billed metered consumption payment was assumed to range from 85% to 100% (an ideal case) with the typical parameter value as 90%

Current operational and maintenance costs

The *current operational and maintenance costs* entail the costs incurred to manage and maintain the current metering system. Parameters pertaining to running costs, such as *billing costs* and management and replacement costs, such as *meter failure and meter replacement costs*, are investigated.

Therefore, Table 4-8 summarizes the *current operational and maintenance cost* parameters for high income areas and their respective ranges. These parameters are further elaborated in the rest of the section.

*Table 4-8: Current operational and maintenance cost*

No	Parameter	Description	Typical	Low	High
3.9	Fraction of demand that is on-site leakage (%)	This is the fraction of the estimated demand that lost to on site leakage	25	5	45
3.10	Ave time between meter readings (/months)	The frequency at which water meters were read	2	1	3
3.11	Meter reading costs (R /meter)	The cost incurred for reading a single water meter. This includes transport, labour, and equipment	8	5	15
3.12	Billing Cost (/bill)	The cost incurred in generating and sending a water bill	10	5	15
3.13	Meter operation & maintenance cost(/meter/month)	The cost of maintaining and operating a single water meter per month	8.33	4.17	16.67
Fraction of meters failing due to					
3.14	Meter failure (%/year)	The failure rates per year of existing water meters	6	2	15
3.15	Vandalism and other (%/year)	The failure rate per year due to vandalism	1.5	0	4
3.16	Total (%/year)	Summation of the failure rate percentage			



Fraction of demand that is on-site leakage (parameter 3.9) represents the fraction of on-site leakage included in the metered consumption. On-site leakage occurs in the consumer's property and is assumed to be any loss of water down-stream side of the consumer's water meter. This therefore includes leakage from pipes, fittings, taps, household appliances etc. (Lugoma, van Zyl & Ilemobade, 2012; Couvelis & van Zyl, 2015).

Previously, with regards to South African context, numerous studies had been done on on-site leakage in low income areas. Lugoma et al. (2012) addressed the need to determine on-site leakage in higher income areas. In this study, selected Johannesburg suburbs were used as the study area. This study revealed that 64% of residential properties had measurable on-site leakage with an average flow rate of 12 kl/month (Lugoma, van Zyl & Ilemobade, 2012). It also found that, like previous studies done abroad, most properties showed little on-site leakage with a few properties having large leakage rates. This is illustrated by Lugoma et al. (2012) as they found that the average on-site leakage rate in Johannesburg study could be reduced by almost two thirds from fixing the leaks in the highest 10% of. The on-site leakage was found to be approximately 25% of the measurable consumption.

McKenzie (2002) reported on projects in Kagiso, Tembisa and Hermanus, where on-site leakage was found to vary between 20 and 35% based on the reduction in demand due to plumbing replacement programmes

In Cape Town, Couvelis & van Zyl (2015) performed a study on the extent on-site leakage in Cape Town. They found that 16.4% of 402 properties investigated in the City of Cape Town had an on-site leakage and their median flow rate was 10 l/hour translating to 7.2 kl/month/property.

Using Australia as a high income country proxy, Beal & Flynn (2014) and Blom et al. (2010) found through case studies that indicate the fraction of on-site leakage on consumption ranging from 6% to 20%. The results from practitioners also revealed that on-site leakage ranges from 5% to 70%.

However, as this also encompasses low income areas, the selected typical value for fraction of on-site leakage on demand was 25% with a range from 10 % to 35%.

Average time between meter readings (parameter 3.10) denotes the frequency at which water meters are currently being read. In South Africa, conventional meters are ideally read once a month (Van Zyl, 2011) though this might not always be the case. Van Zyl et al. (2007) state that not all readings in South Africa are taken on a monthly basis

In Australia, the frequency of reading water meters can be as high as every 3 month (Blom, Cox & Raczka, 2010). In Austria, water meters can be read every 6 months. Using



Australia and Austria as our proxy, this parameter range sets from 1 month to 6 months with 3 months as our typical value.

Based on the surveys, 5 practitioner stated that water meters in South Africa are read on a monthly basis and 1 practitioner stated that meters were read on 6 months basis. However, for this research, any time frame exciding 3 months was found to be excessive.

As such, the typical value for this parameter was selected as 2 months with the low and high values of 1 months and 3 months respectively.

Meter reading cost (*parameter 3.11*) denotes the cost incurred by the municipality to read a single water meter. This includes costs from transportation, labour and equipment.

In a case study 2010 done in Melbourne, it was found that the cost of reading a water meter could cost 60 cents (approximately R4.40 in 2010 and R6.18 in 2016). Studies done by Arregui et al. (2003) and Sternberg & Bahrs (2015) also found that the meter reading cost ranges approximately from R5.50 per meter to R12.69 per meter in 2016.

Based on an interview conducted by Lillian (2016), the cost of reading a meter in Cape Town is approximately R8 per meter. This coincides with the range found from the Melbourne case study.

Therefore, the typical value for this parameter was selected as R8 per meter with a range from R5 per meter to R15 per meter.

Billing cost (*parameter 3.12*) is the cost in generating and sending a bill to the consumer. From a feasibility study done in eThekwin, it was found that the billing cost would amount to R10 per bill. This would comprise of posting (approximately R3 per bill - R4 per bill), administration costs (approximately R6 per bill - R7 per bill) and printing (R1 per bill) (GIBB, 2015).

As such for this parameter, R10 per bill was selected as the typical value with a parameter range of R5 per bill to R15 per bill

Meter operational and maintenance cost (*parameter 3.13*) is the cost accounted for the operation and maintenance of a single meter. It's dictated by the maintenance and operational procedures as well as requirements. The maintenance performed consists of:

- *Corrective maintenance* – The actions undertaken after discovering a fault
- *Preventive maintenance* – Regular inspections and installations to determine the current status of the meter and ensure the meter's patterns is in line with the approval certificate and manufacturers documents



- *Predictive maintenance* – Analysing the meter to establish the optimal replacement frequency. (SGS Economics and Planning, 2011)

Based on an Australian water meter cost benefit study, SGS Economics and Planning (2011) state that the annual maintenance cost should be 15% of the cost of meter. Therefore, taking the cost of a conventional water meter ranges from R150 to R500, the resulting operational and maintenance cost would be range from R22.5 per meter per year - R 75 per meter per year.

In a study to determine the optimal water meter selection system, Johnson (2001) stated that the operational cost of a water meter would be approximately R800. Through the online inflation calculator, this amount would be approximately R2 019.13 in 2016 value terms.

Based on the surveys conducted, 2 practitioners stated that the operation and maintenance cost would be between R70 - R100 while 1 practitioner stated that the cost could be R0. The R0 and R2 019.13 values proof to be extreme cases and not plausible in a practical aspect.

As a result, taking each cost on a monthly basis, the selected typical operational and maintenance cost was chosen to be R8.33 per meter per month (R100 per meter per year) while the range runs from R4.17 per meter per month (R50 per meter per year) to R16.67 per meter per month (R200 per meter per year).

Meter failure (*parameter 3.14*) denotes the meter failure rate in high income areas in a year. This parameter aids in determining the fraction of existing meters that are likely to fail. In so doing, this will help to assess the fraction of water meters that will need to be replaced. As there are different modes of failure, this section looks at the meters that can no longer operate due to technical failure. Failure rate caused by vandalism will be discussed in the subsequent section.

Based on a study done Mutikanga et al. (2011) the failure rate was to be 6.6 %/year. This, Mutikanga et al. (2011), deemed to be a high failure rate. However, in accordance with the survey response of 8 practitioners, 3 practitioners state that the failure rate is 50 %/year, 2 practitioners state that the failure rate is between 20 %/year – 30 %/year and 3 practitioners state that the failure rate is equal and less than 5%. The 3 practitioners that stated 50 %/year were involved in low income metering project. Despite this, the failure rate stated to be between 20 %/year – 30 %/year appears very high for a high income.

As such, the typical failure rate is selected as 6 %/year with 2 %/year and 10 %/year as the minimum and maximum failure rates respectively.



Meter failure rate due to vandalism (parameter 3.15) is the fraction of existing meters that fails to due vandalism. This looks at the intentional acts taken to damage the existing water meters. In South Africa, hostility to water metering arouse when the community felt a sense of inequality when water meters were implemented in their region. In high income areas, vandalism incidents are not as common.

As such, the typical failure rate due to vandalism was assumed to be 1 %/year with a minimum and maximum of 0 %/year to 3 %/year.

Total failure per year (parameter 3.15) is the summation of the both technical meter failure rate per year and meter failure rate per year due to vandalism.



Current social parameters

The *current social parameters* detail the social implications of the existing system on the community. These parameters include *average household income, unemployment rate and volatility of community*. These parameters are needed to establish the consumers' ability to pay and the consumers' affiliation with the water metering system set in place. However, for high income areas, these parameters are seldom documented. As such, these parameters were considered negligible.

Therefore, Table 4-9 summarizes what the *current social* parameters would be and entail for high income areas.

Table 4-9: Current social parameters

No	Parameter	Description	Typical	Low	High
3.17	Average household income (/month)	The average monthly income a household generates			
3.18	Unemployment rate	The unemployment rate of high income areas			
3.19	Volatility of community (No. of protest or mass action incidences per year)	The frequency of protests and similar volatility			



4.3.2.5 Proposed input parameters

This section elaborates on input parameters for a proposed advanced water metering schemes. An alternative option of using conventional metering scheme is used as a measure and control for comparative purposes. This is vital because despite the added benefits, advanced metering schemes are stated in literature to be more costly and complex to implement. However, numerous sources, particularly in developed countries, also indicate that the implementation costs are worth it and will be regained.

The results of the two schemes will then be compared and analysed using sensitivity analysis procedures. These results will then serve as a crucial tool to aid decision makers in choosing the appropriate metering solution for the needs that are to be addressed. These results will be further discussed in chapter 5.3.3

Proposed System Parameters

Proposed system parameters discuss the technical parameters of both conventional and advanced meter implementation schemes. These parameters note the type of meter used (e.g. *meter model*), service lifespan of the meter and its components (e.g. *battery service life*) and failure rates of each meter (e.g. *water meter failure rate*). *SANS 1529-1* and *SANS 1529-9* are vital parameters as they outlining if each meter meets the required standards.

Therefore, Table 4-10 summarizes the *proposed system parameters* for high income areas and their respective ranges. These parameters are further elaborated in the rest of the section.

*Table 4-10: Proposed system parameters*

No	Parameter	Description	Conventional Metering			Advanced Metering		
			Typical	Low	High	Typical	Low	High
4.1	Meter make	The name of the meter's manufacturer						
4.2	Meter model	The name and type of water meter						
4.3	SANS 1529-1 /SANS 1529-4 compliant?	This parameter is a check to note that the meter adheres to the SANS 1529-1 or SANS 1529-4 standards depending on the diameter.						
4.4	SANS 1529-9 compliant?	This parameter is a check to note that the meter adheres to the SANS 1529-9 standards.						
4.5	Mean battery life (years)	The average battery life span in an advanced water meter.				10	3	15
4.6	Battery replaceable in field?	This parameter is a check to note if the battery can be replaced in field.						
4.7	Meter service life (years)	The average meter service lifespan	15	5	25	10	5	20
4.8	Effective service life (years)	The service lifespan of the whole metering (i.e. a meter with a battery)	15	5	25	10	3	20



Fraction of meters expected to fail:								
4.9	Water meter failure (%/year)	The expected failure rate per year of the water meters after implementation	6	2	10	6	2	10
4.10	Electronics and other components (e.g. valve) failure (%/year)	The expected failure rate per year of the added components (e.g. Electronics, valves)				8	2	12
4.11	Vandalism (%/year)	The expected number of meters that will be damaged due to vandalism	1.5	0	4	1	0	2
4.12	Other (%/year)	Other modes of failure that may affect the meter						
4.13	Total	Summation of all percentages pertaining to the meter failure modes.						



Meter make (*parameter 4.1*) denotes the name of the manufacturer that made the water meter. This parameter serves to track the origin and source of the water meter and corresponding products. As is illustrated by the Sensus products in chapter 4.3, the manufacturer's name can be part of the product name. There are no value ranges for this parameter

Meter model (*parameter 4.2*) denotes the type of water meter used in a meter implementation scheme. As is discussed in Literature Review (Chapter 2), water meters are primarily categorized by the manner in which water flow is measured (i.e. volumetric or velocity meters). For advanced meters, they are additional categories such as communication methods (AMR or AMI) and other capabilities (e.g. valve). There are no values ranges for this parameter.

SANS 1529-1/ SANS 1529-4 compliant (*parameter 4.3*) is a check to examine whether a water meter meets the minimum South African metrological standards (SABS, n.d.). The metrology describes the measuring capability of a water meter as is detailed in chapter 2.5.

Based on the diameter of the water meter, the two standards apply. For water meters with a diameter up to 100mm (residential meters), the SANS 1529-1 applies. However, for water meters with a diameter exceeding 100mm but not exceeding 800mm (commercial and industrial meters), SANS 1529-4 is enforced.

There are also international standards that apply to water meters such as ISO 4064 and EN 14154 which all meters sold or bought internationally must adhere to. However, the scope of this research and framework focuses on South African manufacturers and products and as such South African standards.

This parameter simply serves to aid decision makers check whether the selected metering option adheres to the South African metrological standards. Its serves no purpose in the sensitivity analysis and as such has no values range.

SANS 1529-9 compliant (*parameter 4.4*) is a check to examine whether the electronic components of a water meter meets the minimum South African standards (SABS, n.d.). This standard applies to advanced water meters as per our definition of advanced water meters in Chapter 1. Similar to the previous parameter, it's imperative that all advanced water meter adhere to this standard prior to implementations.



This parameter serves no purpose in the sensitivity analysis but is simply used to aid decision makers check whether the selected advanced metering option adheres to the South African standards for electronic components. It therefore has no values range.

Mean battery life (*parameter 4.5*) denotes the average life span (in years) of a battery in an advanced water meter while in service. This parameter serves to investigate how long a battery will be in service after implementation.

From literature, it's discovered that most manufacturers state that a battery's life span ranges from 10-15 years as illustrated in Chapter 4. A few manufacturers also quote a value of 20 years. However, Dittrich (n.d.) conducted a study whereby he investigated the different meter batteries available and their potential life span. This study observed how batteries would operate when utilized in different types of meters (e.g. prepayment meters with RF modules).

In his study, Dittrich (n.d.) found that most batteries will have a lifespan ranging from 10-20 years. However, he also noted some batteries have a lifespan of 5 years. Blom et al. (2010) support these findings as they found, from an Australian case study, that batteries have a lifespan ranging from 5-15 years. In accordance with the collected surveys, 2 practitioners indicated that some batteries had a lifespan of 3 years.

As a result, the typical value for this parameters was selected as 10 years with a low and high value of 3 years and 15 years respectively.

Battery replaceable in field (*parameter 4.6*) is a check to examine whether a battery of an advanced water meter can be replaced on site when the lifespan has been exceeded or a fault discovered. The alternative will require the whole meter to be replaced. This parameter therefore serves to engage in the possible costs that will be incurred depending on the meter selected. The cost of replacing a battery and a water meter vary and will be discussed in the subsequent sub-chapter.

This parameter serves no purpose in the sensitivity analysis as it's purely a check on the requirements needed to replace a battery in a meter. Therefore, there is no values range for this parameters.

Meter service life (*parameter 4.7*) represents the average lifespan (in years) of a water meter; both conventional and advanced. This parameter looks to examine the number many years a meter will be in service after implementation.



Conventional and advanced water meters are both stated, by manufactures, to have a lifespan ranging from 10-25 years. However, based on literature, the meter life span ranges from 5-20 years (Davis, 2005; Blom, Cox & Raczka, 2010; Chang, 2012; GIBB, 2015).

GIBB (2015) and (Davis, 2005), indicate that conventional meters are replaced after 10 years due to the decreasing accuracy with length of service. For advanced water meters, Blom et al. (2010) indicates that conventional and advanced meters are replaced after 15 years and 10 years of service respectively.

Therefore, the typical values of conventional and advanced water meter lifespans were chosen as 15 years and 10 years respectively. For conventional meters, the lifespan range from 5-25 years and for advanced water meters, the lifespan ranges from 5-20 years.

Effective service life (years) (*parameter 4.8*) denotes the service life of a water meter with a battery. If the battery cannot be replaced on site, the effective service life will be the lower of the meter or battery's life span. If the battery is replaceable on site or doesn't have a battery, the effective service life is simply the lifespan of the water meter.

Water meter failure (*parameter 4.9*) denotes the fraction of meters expected to fail after implementation. This parameter only looks at the failure rate of the meter excluding possible added components such as battery, transmitters and other components.

As a result, this parameter will be identical for both conventional and advanced meters. This parameter is equivalent to the current system meter failure (*parameter 3.13*). Therefore, typical expected failure rate, for both conventional and advanced meters, is 6% /year with low and high values of 2% and 10% respectively.

Electronic and other components failure (*parameter 4.10*) denotes the expected failure rate per year of added components on an advanced water meter. The components considered for this parameter include transmitters, batteries, data loggers, valves etc.

Though all components have a chance of failing, literature indicates that batteries are the most critical and have the highest chance of fail. Shirley et al. (2014) indicates that an advanced meter and components with a failure rate of 10%/year or more, within the first 10 years, could be considered as catastrophic. However, Seifried & Converse (2009) found, from a study on a meter replacement project, that the failure rate of an advanced water meter can range from 4.76%/year – 11.28%/year due to battery failure.

As a result, the typical failure rate of an advance water was selected as 8%/year with low and high values as from 2%/year and 12%/year respectively.



Metering components are stated to have a failure rate of less than 8%/year (Shirley et al., 2014). However as indicated in the parameter above, battery failure rates range from approximately 4%/year to 12%/year.

Vandalism (*parameter 4.11*) denotes the expected meter failure rates due to vandalism. As stated in parameter 4.11, vandalism rarely occurs in high income areas.

For conventional meters, this parameter is equivalent to parameter 4.11, therefore, the typical value is 1.5%/year with low and high values of 0%/year and 4%/year.

For advanced water meters, the vandalism is lower than that of conventional meters as some are equipped with tamper alarm systems. As such the typical value is stated as 1%/year with low and high values of 0%/year and 2%/year

Other failure modes (*parameter 4.12*) is a percentage given by practitioners on the field denoting other failure modes not mentioned or considered in the evaluation framework.

As such, for the purposes of this research, this parameter is not allocated a typical value or parameter range.

Proposed Cost Parameters

Proposed cost parameters discuss the costs incurred for implementing, operating and maintaining a selected metering scheme. These entails the cost of purchasing and installing a meter along with its supporting infrastructure (e.g. *meter price, communication infrastructure cost*) and the cost of operating and maintaining the system (e.g. *billing cost, meter operation and maintenance cost, meter replacement cost*).

Therefore, Table 4-11 summarizes the *proposed cost parameters* for high income areas and their respective ranges. These parameters are further elaborated in the rest of the section.



Table 4-11: Proposed cost parameters

No	Parameter	Description	Conventional Metering			Advanced Metering		
			Typical	Low	High	Typical	Low	High
4.14	Meter price (R/meter)	The cost of purchasing a water meter based on the metering scheme selected.	300	150	500	2000	500	5000
4.15	Installation cost (R/meter)	The cost of incurred of installing a water meter based on the metering scheme selected.	650	150	1000	2000	500	3500
4.16	Communication infrastructure cost (R)	The total cost of communication infrastructure if required for advanced water metering system.				1 500 000	500 000	3 000 000
4.17	Payment infrastructure cost (R)	The cost of setting up a payment infrastructure based on the metering scheme selected. This includes vending terminals, billing software, specialized personnel and computer hardware				150 000	50 000	300 000
4.18	Battery replacement cost (R/meter)	The cost of replacing a battery per meter.				350	200	500
4.19	Meter reading cost (R/meter)	The cost of reading a meter based on the metering scheme selected.	8	5	15	5	0	12
4.20	Meter operation & maintenance cost (/meter/month)	The cost of running and maintaining a water meter per month based on the metering scheme selected.	8.33	4.17	16.67	25	6.25	62.5
4.21	Billing cost (R/bill)	The cost incurred of generating and sending a single bill based on the metering scheme selected.	10	5	15	0.25	0	0.75
4.22	Additional billing system operating cost (R/month)	Additional billing operational cost not included in the model						
4.23	Additional communication system operating costs (R/month)	Additional communication operation cost not included in the module						



Meter price (R/meter) (parameter 4.14) is the cost of purchasing a single water meter. This is the price the municipality will pay to purchase a water meter.

GIBB (2015) state that the cost of purchasing a conventional water meter is R 150/meter. This price appears to close to the low limit as 6 practitioners surveyed state that the price ranges between R300/meter – R 750/meter. In Australia, a study in 2010 showed that the cost of a conventional water meter was AUD 36 (Blom, Cox & Raczka, 2010). In 2016, this price equates to approximately AUD 40.61/meter (Reserve Bank of Australia, 2016) and R 426.33/meter in South African currency.

With regards to advanced meters, 6 practitioners state that the price ranges from R500/meter – R2500/meter, with the most stated value as R2000/meter. In Australia, the cost of an advanced water meter in 2010 was AUD 750 (Blom, Cox & Raczka, 2010). In 2016, this price equates to approximately AUD 846/meter and R 8881.35/meter in South African currency. However, this value is seen as too high in South African context.

Therefore, for conventional meters, the typical value is R 300/meter with a price range of R150 per meter – R500 per meter. Whereas for advanced water meters, the typical value is R2000 per meter with a price range of R 500 per meter – R 5000 per meter.

Installation cost (R/meter) (parameter 4.15) is the cost of installing a water meter.

For conventional meters, this cost encompasses the labour costs incurred in installing the meter. GIBB (2015) states that the cost of installing a conventional water meter is R 1000/meter. From the surveys collected, 5 practitioners state that the cost of installing a conventional meter ranges from R 150/meter – R 1000/meter with majority of the values ranging from R 400 per meter – R 1000 per meter. Whereas in Australia, in 2010, the cost was AUD 25 per meter (Blom, Cox & Raczka, 2010). This equates, in 2016 values, to AUD 28.20 per meter and R 296.05 per meter in South African currency.

Therefore, the typical value of installing a conventional meter was selected as R 500 per meter with a range of R 150 per meter to R 1000 per meter

However, with regards to advanced meters, the cost of installing a meter will consist of the cost of installing and setting up the necessary software and communication system per meter, the highly qualified technician labour costs as well as payment infrastructure.

In Australia, water meters were installed with transmitters at each home. The cost, in 2010, was stated as AUD 200. These values translate to AUD 225.60 per meter in 2016 and R2, 368.39 per meter (Blom, Cox & Raczka, 2010).



As a result, the typical value of installing an advanced meter was selected as R 2, 000 per meter with a range of R 500 per meter to R 3, 500 per meter.

Communication infrastructure cost (*parameter 4.16*) denotes the total cost of establishing the required communication infrastructure. This consist of installing the home user interface, purchasing communication equipment, purchasing the necessary communication software's and establishing a communication infrastructure (e.g. via mobile/cellular, radio frequency etc.)

Sackett & Lake (2014) conducted a feasibility study on the implementation of an AMR water metering system on approximately 500 households. From this study, they that the cost of installing an either mobile communication system or fixed (e.g. radio frequency) communication system would range from \$ 21, 500 to \$76, 586. In 2016 values, this equates to approximately \$21, 890.70 and \$77, 977.73. In South African currency, these costs range from R290, 468.59 and R1 034 686.

As these values apply to a small community, the prices are expected to be significantly higher for a larger are. As such, based on the value range of the number of properties in this research, the typical value for this parameter is considered as R1 500 000 with a low and high values of R500 000 and R3 000 000 respectively.

Payment infrastructure cost (*parameter 4.17*) pertains to the cost of setting up a payment infrastructure based on the metering scheme selected. This includes billing software, specialized personnel, and computer hardware.

For conventional meters, it's assumed that the implemented meters will use the existing payment infrastructure. As such, this is not take into consideration. However, for high income areas, the estimated typical value is R100 000 with a range from R50 000 to R300 000.

Battery replacement cost (*parameter 4.18*) is the cost of replacing a battery in an advanced water meter. As discussed in parameter 4.6, a battery can either be replaced separately on site or will require the whole meter to be replaced. This parameter entails the cost of replacing a battery the cost of disposing the batter and the labour cost required.

Based on a study done on eThekwini, GIBB (2015) states that the cost of replacing a battery is R197 per meter. Two surveyed practitioners stated that the cost of replacing a battery were R200 per meter and R300 per meter. Using America as a high-income area proxy, it was found that the cost a battery, in 2013, was \$15 per meter. This equates, in 2016 values, to \$15.52 per meter and R205.59 per meter in South African currency. However, as this is only the cost of the battery and doesn't include the other costs associated with replacing the battery, this value is expected to rise and approximately exceed R 300 per meter.



As such, the typical value selected for this parameter is R 350 per meter with a low and high values of R 150 per meter and R 500 per meter respectively.

Meter reading cost (*parameter 4.19*) is the cost incurred by the municipality in reading a single water meter.

For conventional meter, this cost is equivalent to parameter 3.10. As such, the typical cost selected is R8 per meter per month with a low and high value of R5 per meter per month and R15 per meter per month respectively.

With regards to advanced water meters, meter reading costs vary based on the type of advanced metering used (i.e. AMR or AMI).

For AMRs, meter readings cost would consist of petrol costs and labour cost as readings are taken through drive by or walk by. Sackett & Lake (2014) conducted a feasibility study in Oak Creek, Colorado, of the costs associated with implementing different types of advance water metering systems. In this study, they found that the cost of reading an AMR ranged from \$0.50 per meter per month – \$0.80 per meter per month. In 2016 values, these equate to \$0.51 per meter per month - \$0.88 per meter per month and R6.76 per meter per month – R11.66 per meter per month in South African values. Mott-MacDonald, (2007) proposed that the cost of reading an advanced meter after implementation would be £0.25 per meter per month. In 2016 values, this equates to £0.3 per meter per month and R5.19 per meter per month

With regards to AMI, literature such as Blom, Cox & Raczka, (2010), indicate that meter reading cost could be eliminated due to technologies such as wireless communication networks. However, Blom, Cox & Raczka, (2010) also states that the cost would be replaced by the cost of maintaining this networks.

Thus, the typical metering cost for advanced meters is R6 per meter per month with the low and high value as R0 per meter per month and R15 per meter per month respectively.

Meter operation & maintenance cost (*parameter 4.20*) denotes the cost accounted for the operation and maintenance of a single meter.

For conventional meters, the maintenance and operational costs is equivalent to current operation and maintenance cost (*parameter 3.12*). Therefore, the typical was selected to be R8.33 per meter per month (R100 per meter per year) while the low and high were selected as R4.17 per meter per month (R50 per meter per year) and R16.67 per meter per month (R200 per meter per year) respectively.

For advanced water meters, the operational and maintenance cost is assumed to be 15% of the typical cost of an advanced meter SGS Economics and Planning (2011). Taking the



typical cost range from R500 per meter to R2000 per meter (*parameter 4.14*), the typical operational and maintenance cost was selected as R 25 per meter per month (R300 per meter per year) with low and high values of R6.25 per meter per month (R75 per meter per year) and R62.5 per meter (R750 per meter per year) respectively.

Billing cost (*parameter 4.21*) is the cost assigned to generating and sending a water bill. For conventional meters, this parameter is similar to parameter 3.11 (billing cost for the current systems). Therefore, the typical value for this parameter is R10 per bill with a low and high value of R5 per bill and R 15 per bill respectively.

For advanced water meter, a water bill is either sent through an SMS, email or social media (Britton, Stewart & O'Halloran, 2013). In South Africa, there are service operators that can allow for Bulk SMS at set price range per SMS. These costs per SMS range from R0.20 per SMS to R0.50 per SMS. As the communication and data transfer infrastructure will be in place, there will be no expenses on bill sent through emails or social media.

As a result, the typical value for these parameters is R0.25 per bill with a high and low value of R0 per bill and R0.50 per bill

Additional billing system operating cost (*parameter 4.22*) pertains to addition billing system operating cost not included in the module. This parameter is not used in the sensitivity analysis but allows the framework use to incorporate any cost not included in the model

Additional communication system operating costs (*parameter 4.23*) pertains to addition communication system operating cost not included in the module. Similar to the previous parameter, this cost is not used in the sensitivity analysis but allows the framework use to incorporate any cost not included in the model



Proposed Expected Consumption Parameters

The *proposed expected consumption parameters* detail the expected changes in consumption that would be expected after implementation of a chosen metering scheme. This parameter is used to aid the decision makers in assessing the new consumption pattern in the study or implemented area and from it incorporate the new expected income to the municipality.

For majority of these parameters, the values and ranges will be equivalent to current parameters. This approach was taken to have the same boundaries where literature does not state otherwise. However, for parameters such as *average time between meter readings*, there will be a difference between conventional metering schemes and advanced metering schemes

Therefore, Table 4-12 summarizes the *proposed expected consumption parameters* for high income areas and their respective ranges. These parameters are further elaborated in the rest of the section.

*Table 4-12: Proposed expected consumption parameters*

No	Parameter	Description	Conventional Metering			Advanced Metering		
			Typical	Low	High	Typical	Low	High
4.28	Billed metered consumption (%)	The expected percentage of the total properties in a study area who are billed due to their metered consumption	97	90	100	97	90	100
	Billed metered unit consumption (kl/property/month)	The expected amount of water that accounts for unit billed metered consumption	27	11.25	85.5	23.4	7	83.25
4.29	Billed unmetered consumption (%)	The expected percentage of the total properties in a study area who are billed due to at a fixed rate. This however does not apply to high income areas						
	Billed unmetered unit consumption (kl/property/month)	The expected amount of water for the billed unmetered bracket. This however does not apply to high income areas						
4.30	Illegal or unbilled connections (%)	The expected percentage of the total properties in a study area that have illegal connection to the water network or are not billed for their consumption.	3%	0%	10%	3%	0%	10%
	Illegal or unbilled unit consumption (kl/property/month)	The expected amount of water that accounts for unit illegal or unbilled consumption	3	0	9	3	0	9
4.31	Total	Summation of percentages						



4.32	Number of meters installed	The number of meters installed for the selected proposed metering scheme. Equivalent to the billed metered consumption properties	97%	90%	100%	97%	90%	100%
Fraction of properties paying								
4.33	Billed metered consumption payment rate (%)	The expected percentage of metered properties that are willing to pay	90%	85%	100%	90%	85%	100%
4.34	Average time between meter readings (months)	The expected frequency at which meters will be read	2	1	3	1	0.25	2



Billed metered consumption (*parameter 4.28*) identifies the expected properties in a study area that will be subject to the billed metered tariffs after implementation of proposed schemes

Similar to the *billed metered consumption* stated in *parameter 3.1*, the typical value is assumed to be 95% of the total properties with a range from 90% to 100% of the total properties. These values apply to both conventional and advanced meters

Illegal or unbilled consumption (*parameter 4.30*) identifies the expected connections illegally tapping into the network or consumption that will not be metered due to human intervention (e.g. surpassing the water meter).

Similar to the *illegal or unbilled consumption* stated in *parameter 3.3*, the typical value is assumed to be 3% of the total properties in a study area whereas the low and high values are 0% and 10% respectively. These values apply to both conventional and advanced meters

Unit consumption denotes the expected amount of water utilized or lost per month by each consumption group.

It's assumed that the on-site leakage will be mitigated prior to the implementation of new meters. From the current situation parameters, *fraction of demand that is on-site leakage* (*parameter 3.9*) was taken to range from 5% to 45% with the typical value of 25%. That would mean that the registered water consumed increased by these percentages. As such, mitigating on-site leakage would result in the reduction of registered water consumed.

However, it's worth noting that fully mitigating on-site leakage can prove to be very difficult. For example, leaks can be located in regions where it would prove to be more expensive to correct (Lugoma, van Zyl & Ilemobade, 2012). Leaks can also occur with the households such as leaking taps which are left to the consumer's discretion to mitigate them.

As such, it's assumed not all leaks will be mitigated when the new meters are installed. For conventional meters, it's taken that the reduction in unit consumption will result solely from mitigation of leaks. The reduction range is assumed to vary from 5% to 25% with the typical value taken as 10%.

As for advanced water meters, reduction in unit consumption incorporates the mitigation of leaks as well as reduction in consumer intake due to consumption feedback. With regards to mitigation of leaks, the same percentage assumed for conventional meters will also apply here. As for reduction in consumer intake due to consumption feedback, literature was used to determine the percentage reduction. S nderlund et al., (2016) conducted a study to review the existing literature showing the correlation between reductions in consumption and advanced



metering feedback. The study concluded that reduction in consumption due to advanced metering feedback ranges from 2.5% to 28.6% with an average of 12.15%.

Therefore, for both proposed systems, unit consumption ranges were calculated as the *current unit consumptions (parameter 3.1)* minus the reduction in consumption percentages respectively. To accommodate for the widest parameter spectrum, the high percentage in consumption reduction was deducted from the low current unit consumption to obtain the lowest expected unit consumption. The reverse is also true in obtaining the high unit consumption for both systems. The typical expected unit consumption was calculated as the difference of the typical current unit consumption minus the typical and average reduction in consumption percentages.

Table 4-13: Expected unit consumption for both proposed systems

Description	Conventional Meters			Advanced Meters		
	Typical	Low	High	Typical	Low	High
Billed metered unit consumption	27	11.25	85.5	23.4	7	83.25
Illegal or unbilled properties	3	0	9	3	0	9

Table 4-13 below displays the expected unit consumption for both proposed systems. For conventional systems, the expected typical unit consumption is 27 kl per month with a range from 9.75 kl per month to 85.5 kl per month. As for advanced metering systems, the typical unit consumption is 23.4 kl per month with a range from 5.5 kl per month to 83.25 kl per month.

Reduction to consumption, through any form, has no impact with regards to illegal or unbilled properties. As such, the unit consumption lost to illegal and unbilled properties equivalent to that the registered in current situation as is illustrated in Table 4-13.

Number of meters installed (*parameter 4.32*) denotes the number of meters installed for the selected proposed metering scheme. This parameter is essential to determine the billed metered consumption for the new system

This parameter was taken to be equivalent to that of the current system for both proposed schemes. As such the typical value is 97% of the total properties in a study area are metered whereas the low and high values are 90% and 100% of the total properties respectively.

Billed metered properties payment rate (%) (*Parameter 4.33*) pertains to the percentage of metered properties in the study area willing to pay for the water consumed.



Though literature indicates an increase in conservation patterns when advanced meters were introduced, there wasn't any literature found on the effects these proposed schemes have on payment behaviour.

As such, for both proposed schemes, the payment rate was assumed to be similar to the current systems payment rate. Therefore, the typical payment rate was taken as 90% of the billed metered consumption with a low and high of 85% and 100% of the billed metered consumption.

Average time between meter readings (months) denotes the expected frequency at which meters will be read.

For conventional meters, the meter reading frequency will be similar to the current system. Therefore, the typical value will be 2 months with a minimum and maximum value of 1 month and 3 months respectively.

As for high income areas, literature indicates that for a fixed advanced system (AMIs) meter readings can be taken on an hourly basis. However, without a fixed communication structure between the utilities and the meter, meters can be read on a weekly - monthly through drive by (AMRs) (Marchment-Hill, 2010). As such, the typical value will be 1 months with a minimum and maximum value of 0.25 month (weekly basis) and 2 months respectively.

4.3.3 Framework results

4.3.3.1 Introduction

Once the input parameters are entered into the framework, results are generated which can then be analysed. This section describes the output results and the calculations used to generate these results.

Due to complexity of the problem being tackled, the output results could not be simplified to a single figure or ranking. This would not provide a holistic view of the performance of each scheme and mislead municipalities and other decision makers on the success or failure of each scheme.

The evaluation framework was designed to highlight the key and crucial outputs that reflect the effects of each scheme and display the score that each output achieved. These scores are illustrated in Table 4-14. As indicated in this table, scores would rank from "very bad", which would indicate catastrophic failure, to "very good", which indicates the ideal result. Results scored as "unrealistic" should not be trusted and the parameters input into the framework will need to be verified.

Table 4-14: Score of the evaluation results

Very bad
Bad
Neutral
Good
Very good
<u>Unrealistic</u>

The results, displayed in the framework, were grouped in accordance to the four performance criteria (technical, social, environmental, and economic) that each metering options are to be gauged on. This was also done to meet the research objective of assessing the performance feasibility of a proposed metering scheme on these criteria and provide a more holistic view on the failure and success of each scheme.

The subsequent sections describe the calculations set up under each criterion that are performed on the input parameters. Typical outcomes will also be presented for each performance criteria.

4.3.3.2 Technical

Technical results gauge the performance of the in-built mechanism of each metering option. Table 4-15 summarizes each output results and further discusses them in the rest of the section.

Table 4-15: Technical evaluation outputs

No	Parameter	Description
1.1	SABS compliance	Whether the meter meets the SABS standards
1.2	Number of meters to replace (/month)	Average number of failure meters replaced in each month

SABS compliance (result 1.1) gauges whether a proposed meter meets the minimum metrological requirements of the South African Bureau of Standards (SABS).

As illustrated in the proposed system parameters section, a conventional meter must meet either SANS 1529-1 or SANS 1529-4 depending on the diameter size of the meter. For an advanced meter, they must meet the aforementioned standards in addition with the SANS 1529-9.

If the result indicates “TRUE” then this is a very good result. However, if the result indicates “FALSE”, then this is a very bad result and should not be considered.



Number of meters to replace (result 1.2) indicates the average number of failed meters that need to be replaced in a month. This is determined by the calculation below.

$$\text{Number of meters replaced} = \frac{\text{Total \% failure rate (\%/year)} \times \text{Number of meters installed}}{12} \quad 4-2$$

The product of *total % failure rate* (parameter 4.13) and the *number of meters installed* (parameter 4.32) gives the average number of meters to fail in a year. This value is then converted to the average number of meters to fail in a month.

4.3.3.3 Social

This section discusses the key social effects of implementing a metering scheme to the community. Table 4-16 summarizes the social evaluation results.

Table 4-16: Social evaluation outputs

No	Parameter	Description
2.1	Current rate of meter vandalized (%/year)	The current rate of water meters failing due to vandalism.
2.2	Average water bill (R/month)	The average cost of a water consumed per month.

The purpose of social results is to gauge how receptive society will be to the implementation of new metering schemes and technologies. In some societies, increase in expenses (water bill) as well as restrictions to services considered to be fundamental can prompt negative community reaction to the technology. However, for high income areas, this is not considered as a major factor as its assumed residents are well and able to pay the required water bill.

4.3.3.4 Environmental

Environmental results address the impact that each metering scheme will have on the environment after implementation. To assess the environmental impact of the proposed schemes, *reduction in consumption* and *number of meter batteries disposed* are taken as the key indicators.

Table 4-17 summarizes each component of the output results and further discusses them in the rest of the section.

**Table 4-17: Environmental evaluation outputs**

No	Parameter	Description
3.1	Billed metered consumption (kl/month)	An outline of the amount of water consumed by the current and projected billed metered properties.
3.2	Billed unmetered consumption (kl/month)	An outline of the amount of water consumed by the current and projected billed unmetered properties. This result is not considered in high income areas.
3.3	Illegal consumption (kl/month)	An outline of the amount of water consumed by the current and projected illegal properties.
3.4	Total consumption (kl/month)	An outline of the total current and projected water consumptions in the study area.
3.5	Unit consumption (kl/property/month)	The current and projected water consumptions per property in the study area.
3.6	Reduction in consumption (kl/month)	The reduction in consumption of after implementation of the proposed conventional and advanced water metering systems with respect to the current system.
3.7	Fractional reduction in consumption (%)	The reduction in consumption of the proposed systems expressed as a percentage of the total consumption of the current system
3.8	No of batteries to dispose (/year)	The average number of batteries that will need to be safely disposed if the advanced water metering is implemented.

Billed metered consumption (result 3.1) denotes the amount of water consumed for both current and projected metered billed metered properties.

This is calculated as indicated by the following equations

$$\begin{aligned}
 &\text{Billed metered consumption (Current)} \\
 &\text{(Kl/month)} = \text{Number of metered properties} \times \text{Unit billed consumption} \\
 &\quad \times (1 - \text{meter under registration \%})
 \end{aligned}
 \tag{4-3}$$

$$\begin{aligned}
 &\text{Billed metered consumption (Proposed)} \\
 &\text{(Kl/month)} = \text{Number of metered properties} \times \text{Unit billed consumption}
 \end{aligned}
 \tag{4-4}$$



As is explained under *Meter under registration (parameter 2.4)*, meter under registration needs to be considered due to meter intrinsic errors.

Illegal consumption (result 3.3) denotes the amount of water lost due to the current and projected illegal connections. Like equation 3, illegal consumption is determined through the product of the amount of illegal properties and the unit illegal consumption.

Unit consumption (result 3.5) denotes the current and projected water consumption per properties. This is determined as the quotient of the *Total consumption (results 3.4)* over the *Total number of properties (parameter 2.1)* in a study area

Reduction in consumption (result 3.6) examines the reduction of water consumed after implementing either the proposed conventional or advanced metering scheme with respect to the water consumption of the current metering system. This is therefore calculated as the difference between the *Total consumption (result 3.4)* of the individual proposed schemes and the *Total consumption (result 3.4)* of the current metering system.

$$\begin{aligned} \text{Reduction in} \\ \text{Consumption} \\ (\text{Kl/month}) \end{aligned} = \Delta \text{Total consumption (Current system – Proposed system)} \quad 4-5$$

Fractional reduction in consumption (result 3.7) denotes the percentage of the reduction in consumption of either of the proposed systems in relation to the current system consumption. This is simply the quotient of the *reduction in consumption (result 3.6)* over the *total consumption for the current system (result 3.4)*.

As this is one of the key result, the score below was used to determine effect of each scheme

Table 4-18: Effect score for reduction in consumption

Score	Criteria
Very Bad	<0%
Neutral	0%-3%
Good	3%-20%
Very Good	>20%

As one of key initiative for implementing new water meter scheme is the reduction of consumption, it's imperative that the proposed scheme result in reduction in consumption.



Therefore, increase in consumption would mean that the metering scheme failed to achieve the required environmental goal.

It's assumed that upon installation of new water meters, leaks found around the meter will be mitigated. As such, the neutral score is stated to range from 0% to 3%. Based on studies conducted on reduction to consumption due to consumption feedback techniques, S nderlund et al., (2016) state that reduction in consumption ranged from 2.5% to 28.6% with the average as 12.15%. This was used to set the good score within the range of 3% to 20%. Reduction in consumption larger than 20% could be deemed as very good score.

Number of batteries to dispose (result 3.8) is the total number of failed batteries that will need to be disposed in a year. As batteries contain electrolytes that would be harmful to the environment (AlAbdulkarim, Lukszo, & Fens, 2012), it's imperative to know determine how many batteries will be disposed after their service life has expired. This is determined as the quotient of the *number of meters installed (parameter 4.32)* over the *mean battery lifespan (parameter 4.7)*

As no literature was found that indicated the critical point to which number of batteries would be harmful to the environment, the score demonstrated below was based on the typical number of batteries used as a baseline. As the typical value is 194 batteries per year, neutral range will be $\pm 15\%$ of the typical value (approximately 164 batteries to 223 batteries). For good and bad score, the range will be from -15% to -50% (97 batteries to 164 batteries) and +15% to +50% (223 batteries to 291 batteries) respectively. These percentages are assumptions based on the expected number that might pose a threat to the environment. Ranges beyond the good and bad range are then classified as very good or very bad

Table 4-19: Effect score for number of batteries disposed

Score	Criteria
Very Bad	>291 batteries
Bad	223 batteries – 291 batteries
Neutral	164 batteries – 223 batteries
Good	97 batteries – 163 batteries
Very Good	< 163 batteries

4.3.3.5 Economic

Economic results gauge the amount of income collected through the proposed systems with the expenses incurred through implementing and utilizing these systems.



Income collected through metering of services (gas, water, electricity) act as the main source of finance for the utilities to operate and maintain these service systems as well as expand when required. However, new metering systems have the potential of requiring high initial capital costs as well as high operations and maintenance cost. These would not make the systems sustainable and hence not viable for implementation.

Therefore, *capital payment period* and *effective surplus* are taken as key indicators to assess the economic feasibility of each proposed system.

Table 4-20 summarizes each component of the output results and further discusses them in the rest of the section.

Table 4-20: Environmental evaluation outputs

No	Parameter	Description
Income		
4.1	Billed metered consumption (R/kl/month)	The expected income received from metered properties of the current and proposed systems.
4.2	Billed unmetered consumption (R/kl/month)	The expected income received from billed unmetered properties of the current and proposed systems. This parameter is not considered for high income areas
4.3	Total Income (R/kl/month)	A summation of all the income collected from current and proposed systems.
4.4	Unit Income (R/kl/property/month)	The amount of income collected per property per month for current and proposed systems in the study area.
4.5	Increase in income (R/kl/month)	The increase in income after the implementation of the proposed conventional and advanced water metering systems with respect to the current system.
4.6	Fractional increase in income (%)	The increase in income of the proposed systems expressed as a percentage of the total consumption of the current system
Capital cost		
4.7	Water meter (R/meter)	The initial capital costs of purchasing water meters installed for each metering option.
4.8	Installation (R/meter)	The cost of installing new meters for each metering scheme
4.9	Communication infrastructure costs (R)	The cost to put in place the communication infrastructure required. This is strictly for advanced water meters
4.10	Payment infrastructure costs (R)	The cost of setting up the required payment infrastructure



4.11	Total capital cost (R)	A summation of all capital costs incurred by the municipality
4.12	Unit capital cost (R/property)	The capital cost incurred per property for both proposed systems in the study area
Operational cost		
4.13	Water Production (R/month)	The cost of producing the water supplied and consumed
4.14	Meter reading (R/month)	The monthly cost of meter readings for each metering system
4.15	Meter operational & maintenance cost (R/month)	The monthly cost operating and maintaining each metering system
4.16	Billing cost (R/month)	The cost of generating consumption bills per month
4.17	Billing system operating cost (R/month)	The monthly cost of running and maintaining the installed billing systems.
4.18	Communication system operating cost (R/month)	The monthly cost of running and maintaining the communication system
4.19	Failed meter replacement cost (R/month)	The cost of replacing failed meters in a month
4.20	Battery replacement cost (R/month)	The cost of replacing failed meter batteries in a month
4.21	Total operating cost (R/month)	The total operational cost for each metering system in a month
4.22	Unit operating cost (R/property/month)	The operational and maintenance cost per property in a study area per month
4.23	Decreasing operating cost (R/month)	The decrease in total monthly operational cost of the proposed metering systems in comparison to current system
Summary		
4.24	Operational surplus (R/month)	The monthly surplus (calculated as the difference between income and operational costs) of current and proposed metering systems.
4.25	Increased operational surplus (R/month)	The increase in operational surplus of the proposed systems in comparison to the current system
4.26	Capital payback period (months)	The duration taken to recover initial investment to install and implement given the operational surplus of each proposed metering option.
4.27	Expected service life (years)	The expected service life span of each proposed metering option



4.28	Effective surplus (R/month)	The average monthly surplus, considering both capital and operational costs, over the service life of each proposed metering option
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Billed metered consumption income (result 4.1) is the expected income received from billed metered properties. This is simply calculated as the product of *billed metered consumption* (result 3.1), *billed metered consumption payment rate* (parameter 4.33) and *applicable water tariff* (parameter 2.3) as illustrated by the equation below

$$\begin{aligned} \text{BMC Income} &= \text{BMC} \times \text{BMC payment rate} \times \text{applicable water tariff} \\ (\text{R/Kl/month}) & \end{aligned} \quad 4-6$$

Unit income (result 4.4) is the amount of income collected per property per month for both current and proposed metering systems in the study area. This is determined as the quotient of *total income collected* (result 4.3) and *number of properties* (parameter 2.1) in the study area. This is displayed in the equation below.

Increase in income (result 4.5) is the rise total income from the implemented proposed systems as compared to current systems. This is calculated by getting the difference of *the total income from the individual proposed systems* (result 4.3) and *the total income from the current system* (result 4.3).

$$\begin{aligned} \text{Increase in income} &= \Delta \text{Total Income}(\text{Proposed system} - \text{Current system}) \\ (\text{R/month}) & \end{aligned} \quad 4-7$$

Fractional increase in income (result 4.6) is the increase in income expressed as a fraction of the total income from the current system.

Capital costs (result 4.7-4.12) are the initial costs needed to install and implement each of the proposed systems. These results are equal the respective *proposed cost parameters*

Water meter cost (result 4.7) is the initial capital cost of purchasing the water meters to be installed in a study area for each metering option. This equates to the product of *number of meters installed* (parameter 4.33) and *the meter price of an individual meter* (parameter 4.14)



Installation cost (result 4.7) is the cost of installing all new meters for each metering scheme. This is taken as the product of the *installation cost of a single meter* (parameter 4.15)

Other capital costs (result 4.8-4.11) are the other initial capital costs needed to install and implement each of the proposed systems. These results are equal the respective *proposed cost parameters*.

Unit capital cost (result 4.12) is the capital cost per property in a study area. This is simply calculated as the quotient of the *total capital cost* (result 4.11) over the *number of properties in a study area* (parameter 2.1)

Water productions (result 4.13) is the cost incurred by the municipality to produce the water supplied and consumed by customers. This result is taken as the product of the *total consumption* (result 3.4) and *water cost price* (parameter 2.2)

Meter reading (result 4.14) is the monthly cost of reading the water meters of each metering scheme in a study area. This is calculated by the equation below.

$$\begin{array}{l} \text{Meter reading} \\ \text{cost} \\ \text{(R/month)} \end{array} = \frac{\text{No. of metered properties} \times \text{Meter reading cost of a single meter}}{\text{Average time between meter readings}} \quad 4-8$$

Meter operational and maintenance cost (result 4.15) is the monthly cost of operating and maintaining the water meters in a study areas monthly. This equates as the product of single *meter operational and maintenance cost* (parameter 4.20) and *number of metered properties* (parameter 3.1)

Billing cost (result 4.16) is the cost of generating water bills for a month. This is taken as the product of the *billing cost of a single bill* (parameter 4.21) and the *number of billed metered properties* (parameter 4.28)

Billing system operating cost (result 4.17) is the cost of operating and maintaining installed billing systems. This result is not considered as it for this research as the parameter required to solve it, *additional billing system operating cost* (parameter 4.22), was not estimated. This parameter was a slot required to be filled by the practitioner and user of these proposed metering systems

Communication system operating cost (result 4.18) is the operational and maintenance cost of the installed communications systems. This result is not considered as it for this research as the parameter required to solve it, *additional communication system operating cost* (parameter



4.23), was not estimated. This parameter was a slot required to be filled by the practitioner and user of these proposed metering systems

Failed meter replacement cost (result 4.19) is the cost of replacing meters that have failed in a month. This equates to the product between the *number of meters failed* (result 1.2) and the sum of the *meter price* (parameter 4.14) and *installation price* (parameter 4.15) of a single meter. This is illustrated by the equation below

$$\begin{array}{l} \text{Failed meters} \\ \text{replacement cost} \\ \text{(R/month)} \end{array} = \text{Number of meters failed} \times (\text{meter price} + \text{installation cost}) \quad 4-9$$

Battery replacement cost (result 4.20) is the cost of replacing batteries that have failed in a month. This equates to the product of *number of batteries disposed per year* (result 3.8) and *cost of replacing a single battery* (parameter 4.18). The solution is then divided by 12 to get the *battery replacement cost per month*.

Total operating cost (result 4.23) is the summation of all the listed operational and maintenance cost

Unit operating cost (result 4.23) is the equivalent total operational and maintenance cost of a single property in the study area. This is simply calculated as the quotient of the *total operating cost* (result 4.23) over the *number of properties in a study area* (parameter 2.1)

Decreased operating cost (result 4.23) is the decrease in operating cost of the implemented proposed systems in comparison with the current metering system. This is calculated by subtracting the *total operating costs* (result 4.23) of the implemented systems from the *total operating costs* (result 4.23) of the current system.

The summary economic results are the key indicators of the economic performance of each metering option. Details of each result will be expounded on as well as calculations illustrated

Operational surplus (result 4.24) is the monthly surplus of the implemented metering system. Primarily this gauges the profits gathered for each metering option. This equates to the difference between the *total income* (result 4.3) and the *total operating cost* (result 4.21) of each metering option.



Increased operational surplus (result 4.25) is the increase in *operational surplus* of the implemented proposed system in comparison the *operational surplus* of the current system. This gauges the changes in profits due to the transition of the new implemented proposed systems.

Capital payment period (result 4.26) is the duration taken for the new implemented systems to pay off the initial capital cost invested in its start up through the income generated. This is an examination of the length of duration required for the accumulated income generated will cover the accumulated income.

For the conventional option, it's largely assumed that the metering option will utilise existing metering systems and infrastructure. It will mostly comprise of upgrades in areas needed and replacement of water meters. This would mean that this option would be expected to have a shorter payback period.

As for the advanced water meters, significant start-up capital will be required as this is a transition to the new metering option and equipment costs for the advanced system are larger than those of conventional system. This would translate to an expected larger payback period.

If the payback period is negative, this would mean that the invested capital would never be regained. This would prove to be the worst-case scenario for a metering system.

Capital payback period is calculated by dividing the *total capital cost* (result 4.11) by the *increased operational surplus* (result 4.25)

$$\begin{array}{l} \text{Capital payment period} \\ \text{(Months)} \end{array} = \frac{\text{Total capital cost}}{\text{Increased operational surplus}} \quad 4-10$$

For this key result, the score in Table 4-21 was used. The ideal result would be invested capital paid back within the average service life of the meter implemented. As such the neutral range is taken from 15 years, average meter lifespan, to 25 years, high value meter lifespan. Bad score would result from a capital payment period exceeding 25 years. Good score would mean capital invested was regained between 7 years to 14 years and very good would result from a capital payment period between 0 years and 7 years. Capital payment period less than 0 years would mean that capital invested would not be regained and this is rated as a very bad score

Table 4-21: Effect score for capital payment period

Score	Criteria
Very Bad	< 0
Bad	>25 years
Neutral	15 years – 25 years
Good	7 years – 14 years
Very Good	0 years – 7 years

Effective surplus (result 4.28) denotes the average monthly surplus over the service life of each proposed metering scheme. This result is designed to be a basis examination of metering options with different service lives. The profits calculated take into consideration the capital and operational costs.

This is done to give a holistic view of the economic performance of each option. For instance, a meter with high capital investments, high payback period and longer service life may not necessarily generate more surplus than a metering option with lower capital option with high incomes and low service life

This output is calculated using the equation below.

$$\text{Effective surplus (R/month)} = \frac{[(\text{Exp. service life} \times 12) - \text{Capital payment period}] \times \Delta \text{ operational surplus}}{\text{Exp. service life} \times 12} \quad 4-11$$

As this result, comparative result on the previous results generated, literature could not be used to specify the score categories. Ideally, a water metering scheme should generate incomes. As such the score simply divided into positive or negative figures are is illustrated in Table 4-22. Negative effective surplus is considered very bad with positive effective surplus as very good. Effective surplus of R 0 value is considered the neutral value however, it's unlikely to occur

Table 4-22: Effect score for effective surplus

Score	Criteria
Very Bad	< R 0
Neutral	R 0
Very Good	> R 0



4.3.4 Typical framework results

4.3.4.1 Introduction

This section serves to present the evaluation framework with the typical input parameters and the consequential generated results. Prior to discussing the typical framework results generated, the typical input parameters are first discussed. Brief explanations are given for the selection of each input value however, detailed discussions on the reasoning behind each value can be found in chapter 6.2.2.

The implication of these results will also be discussed, with special interest on the key results (i.e. number of batteries disposed, reduction in consumption, capital payment period and effective surplus). This is because these key typical results serve as the baselines for the sensitivity analysis conducted and discussed in chapter 6.3

4.3.4.2 Typical input parameters

The subsequent tables presented in this section display the data input portion of the evaluation framework where the input parameters were entered in. Each input parameter category consists of a comment column in which the framework user can note statements about the entries made or changes made to the respective entries.

First entries required by the user of the evaluation framework are the system details and the global parameters demonstrated in Table 4-23 and Table 4-24 respectively

The system details are used to simply identify the project or system to be analysed using evaluation framework.

Table 4-23: System input parameters for typical high income area

1. SYSTEM			
No	Parameter	Value	Comment
1.1	Analysis ID	Typical	
1.2	System name	Typical High Income Results	
1.3	Suburb(s)	Test suburb	
1.4	City	Test City	
1.5	Date	Today	

Global parameters are the core parameters of the project or system. These parameters, demonstrated in Table 4-24, are necessary for analysing the current and proposed metering systems.

For this research, the typical study area was taken comprise of 2000 properties with the water tariff of R17/kl and water cost of R10/kl. Considering that water meters in the current system have been in used for a significant period, meter under registration can be assumed to



occur and as such, for the simplicity of the calculation, the average meter under registration in the system was taken to be a single figure of 5%.

Table 4-24: Global input parameters for typical high income area

2. GLOBAL PARAMETERS

No	Parameter	Units	Value	Comment
2.1	Number of properties		2,000	
2.2	Water cost price	(R/kl)	10	
2.3	Applicable water tariff	(R/kl)	17	
2.4	Meter under registration	(%)	5%	
2.5	Billed unmetered tariff	(R/month)	0	

Following the global input parameters, details of the current situation need to be entered. Current situation is categorized into 3 groups; current water consumption, current payment rate and other current parameters as illustrated in Tables 4-25, 4-26 and 4-27.

Current water consumption entails the income that will be collected from the current metering scheme as well as the amount of water that will be consumed and lost. As illustrated in Table 4-25, unbilled metered consumption is not considered in the framework as it's assumed negligible in high income areas.

The total billed metered consumption, considering meter under registration, is important to obtain the income generated by the current system. For the typical current systems, this parameter is noted to be 55,290 kl/month. The income obtained from the current system will serve as a baseline to compare with the calculated income generated by the proposed systems.

The total consumption of the current system, noted as 58,380 kl/month, serves to help gauge the reduction of consumption after implementing the proposed metering systems

Table 4-25: Current water consumption parameters for typical high income

3. CURRENT SITUATION

Current water consumption

No	Parameter	No of properties	Unit consumption (kl/property/month)	Total consumption (kl/month)	Comment
3.1	Billed metered consumption	1,940	30	58200	
3.2	Billed unmetered consumption	0	0	0	
3.3	Illegal or unbilled connections	60	3	180	
3.4	Total/average	2,000	29.19	58,380	
3.5	Billed metered consumption (meter-under registration)	1940	28.5	55,290	

Current pay rate illustrated in Table 4-25, details the fraction of consumers that will pay for their water consumption and as such the amount of income collected. For a typical system, payment rate for the metered properties was taken to be 90%. This meant that 1746 properties of the 1940 metered properties (illustrated in Table 4-24) will pay for their consumption. This then results to the municipality collecting R845, 937/month from the study area.

**Table 4-26: Current parameters rate for typical high income area****Current payment rate**

No	Fraction of properties paying for water	Fraction	No of paying properties	Income from water sales (R/month)	Comment
3.6	Billed metered consumption	90%	1746	845937	
3.7	Billed unmetered consumption	0%	0	0	
3.8	Total/average	90.0%	1746	845937	

The other current parameters section pertains to parameters that entail the running and operational cost of the current metering scheme as well as maintenance and replacement costs. As stated in the literature review chapter, one of the drivers for implementing advanced metering schemes is lower metering reading and billing cost. For the typical current system, these parameters have the values of R8/meter and R10/meter respectively. However, it should also be noted that meter operational and maintenance cost for the advanced metering scheme is expected to be larger than that of the current system, which is noted to be R8.33/meter.

With regards to the maintenance and replacement cost parameters in the current system, the typical meter failure rate is registered as 6%/year and the typical vandalism rate in a high-income area is noted as 1.5%/meter.

Table 4-27: Other current parameters for typical high income area**Other current parameters**

No	Other parameters	Units	Value	Comment
3.9	Fraction of demand that is on-site leakage	%	25%	
3.10	Ave time between meter readings	(months)	2	
3.11	Meter reading cost	(/meter)	R8.00	
3.12	Billing cost	(/bill)	R10.00	
3.13	Meter operation & maintenance cost	(/meter/month)	R8.33	
Fraction of meters failing due to:				
3.14	Meter failure	(/year)	6.0%	
3.15	Vandalism and other	(/year)	1.5%	
3.16	Total	(/year)	7.5%	

After the current metering scheme segment, the input parameters of the proposed metering scheme are required. This segment contains data on both advanced metering scheme and new conventional metering scheme. The conventional metering scheme acts as a measure and control for comparative purposes to access whether it would be more beneficial to implement an advanced metering scheme or new conventional metering scheme.

Similar to the current system, the first section of the proposed scheme is the proposed system parameters as illustrated in Table 4-28. These parameters entail the make and model of the proposed meters to be implemented and their technical specifications. The technical specifications investigated are the minimum metering standards (known as SANS standards) set by the SABS and the meter and battery lifespan. A typical water meter for both proposed



metering scheme should meet the necessary SANS metrological standards. Advanced meters have an additional SANS standard for the additional electronic component.

The typical meter lifespans for conventional and advanced meters are 15 years and 10 years respectively. For advanced meters, the typical battery lifespan is 10 years.

Meter failure parameters are also noted in the proposed system parameters section. The conventional meter has the same failure rates as those listed for the current system as it's assumed both systems use conventional meters. For advanced meters, the typical water meter failure is taken to be the same as that of the conventional meters. However, electronic and other component failure rate is an additional failure parameter for the advanced meters which has a typical value of 8%/year. The vandalism rate of the advanced meter is less than that of the conventional meters because of tamper proof and tamper alarm capabilities of the advanced meters. The typical value of the vandalism rate is taken as 1%/year.

Table 4-28: Proposed system parameters for typical high income area

4. PROPOSED SCHEME

Proposed system parameters

No	Parameter	Units	Conventional metering (baseline)	Advanced metering	Comment
4.1	Meter make		framework	Smart Meter	
4.2	Meter model		Positive displacement	Unknown	
4.3	SANS 1529-1 compliant?		TRUE	TRUE	
4.4	SANS 1529-9 compliant?			TRUE	
4.5	Mean battery life	(years)		10	
4.6	Battery replaceable in field?			TRUE	
4.7	Meter service life	(years)	15	10	
4.8	Effective service life		15	10	
Fraction of meters expected to fail due to:					
4.9	Water meter failure	(/year)	6.0%	6.0%	
4.1	Electronics and other components (e.g. valve) failure	(/year)		8.0%	
4.11	Vandalism	(/year)	1.5%	1.0%	
4.12	Other failure modes	(/year)	0.0%	0.0%	
4.13	Total	(/year)	7.5%	15.0%	

Proposed costs, illustrated in Table 4-29, entail the costs incurred for implementing each proposed metering scheme and operating each system. First capital costs considered are the meter price and installation costs. For conventional meters, the typical costs are R300/meter and R650/meter respectively. As for advanced meters, the typical purchasing cost is R2000/meter and the typical installation cost is R2000/meter.

As it's taken that current systems are comprised of conventional meters, infrastructure needed for the new conventional metering system are already in place. It's assumed that no major infrastructure replacement need take place and as such communication infrastructure cost and payment infrastructure cost are negligible. For advanced meters, communication infrastructure cost and payment infrastructure cost for a typical system are R1, 500,000 and R150, 000 respectively.



Operational and maintenance cost for the typical advanced meter (R25/meter/month) are anticipated to be higher than that of the typical conventional meter (R10/meter/month). This is due to costs incurred to run and maintain the new and added infrastructure needed to run the advanced metering scheme as compared to the conventional meter.

However, with regards to billing cost and meter reading cost, advanced meters are anticipated to generate less billing cost (R0.25/bill and R5/meter respectively) than conventional meters (R10/bill and R8/meter respectively). Advanced metering system utilize remote meter reading capabilities which reduces the number of intervals taken to read all the meters in the study area.

Table 4-29: Proposed system cost parameters for typical high income area

Proposed system costs

No	Parameter	Units	Conventional metering (baseline)	Advanced Metering	Comment
4.14	Meter price	(R.meter)	300.00	2,000.00	
4.15	Installation cost	(R.meter)	650.00	2,000.00	
4.16	Communication infrastructure cost	(R)		1,500,000.00	
4.17	Payment infrastructure cost	(R)	0.00	150,000.00	
4.18	Battery replacement cost	(R.meter)		350.00	
4.19	Meter reading cost	(R.meter)	8.00	5.00	
4.20	Meter operation & maintenance cost	(R.meter/month)	8.33	25.00	
4.21	Billing cost	(R.bill)	10.00	0.25	
4.22	Additional billing system operating cost	(R.month)	0.00	0.00	
4.23	Additional communication system operating costs	(R.month)		0.00	

The last segment of the input parameters for proposed metering scheme are the expected consumption and meter reading for the proposed systems. For both proposed systems, it's assumed that leaks around the meter the detected and mitigated when installed. As such, for the conventional meter, the typical metered consumption is expected to be 27 kl/property/month. However, advanced meters are noted to have leak detection capabilities as well more immediate, and in some cases, real time responses to user consumption pattern. These capabilities, in addition to leak detection during installation, results in an expected consumption of 23.4 kl/property/month.

**Table 4-30: Propsed consumption and meter reading parameters for typical high income area****Expected consumption and meter reading for the proposed systems**

No	Parameter	Units	No of properties	Conventional metering (baseline)	Advanced metering	Comment
4.28	Billed metered consumption	(kl/property/month)	1,940	27	23.4	
4.29	Billed unmetered consumption	(kl/property/month)	0	0	0	
4.30	Illegal consumption	(kl/property/month)	60	3	3	
4.31	Total	(/average)	2000	26.28	22.79	
4.32	No of meters installed		1940			
Fraction of properties paying for water						
4.33	Billed metered consumption	(%)		90%	90%	
4.34	Billed unmetered consumption	(%)		0%	0%	
4.36	Ave time between meter readings	(months)		2	1	

4.3.4.3 Typical results

The typical results demonstrated in the table below are generated from the typical input parameters entered into the framework through a set of calculations expounded in chapter 6.2.3.

As is discussed in chapter 6.2.3, results with special regards to key results were categorised as based on the score presented in Table 4-14 to note the effect of each scheme

The technical results generated discuss whether the proposed meters are SABS compliant or not and the number of meters that will need to be replaced due to failure. For both typical proposed systems, the water meters are SABS complaint. The number of meters that need to be replaced are 12 meter/month and 24 meters/month for the conventional and advanced metering system

Table 4-31: Technical results for a typical high income area**1. TECHNICAL**

No	Property	Units	Current	Conventional metering (baseline)	Advanced metering
1.1	SABS compliance			Yes	Yes
1.2	Number of meters to replace	(/months)	12	12	24

For high income, social factors and results do not play a significant role as they are used to access the users' and study area community's ability to pay for water and likeliness to riot against the metering scheme installed. It's assumed that in high income users are well and able to pay for water and are likely to riot. However, in the framework, the number of meter vandalised is listed as 1.5% year and the average water bill is noted as R 428,40 per month.

Table 4-32: Social results for a typical high income area**2. SOCIAL**

No	Property	Units	Value
2.1	Current rate of meters vandalised	(/years)	1.5%
2.2	Average water bill	(/months)	R428.40



The environmental results pertain to the current and expected water consumption for the current and proposed systems respectively in order access the reduction in consumption. As is illustrated in Table 4-33 below, typical reduction in consumption percentages are 5.2% and 17.4%. In accordance with the scores stated in Table 4-18, reduction in consumption scores as a good with the reduction caused by high income areas is registered as very good.

With regards to the number of batteries disposed, the typical value of 194 batteries/ year is registered as a neutral score.

Table 4-33: Enviromental results for a typical high income area

3. ENVIRONMENTAL

No	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(kL/month)	55,290	52380	45396
3.2	Billed unmetered consumption	(kL/month)	0	0	0
3.3	Illegal consumption	(kL/month)	180	180	180
3.4	Total consumption	(kL/month)	55,470	52560	45576
3.5	Unit consumption	(kL/property/month)	27.74	26.28	22.788
3.6	Reduction in consumption	(kL/month)		2,910	9,894
3.7	Fractional reduction in consumption	-		5.2%	17.8%
3.8	No of batteries to dispose	(/year)			194

The economic results, displayed in Table 4-34, consider the income generated by the metering schemes and deducts the capital costs invested into each scheme as well as the running costs. Calculations for this section can be noted in chapter 6.2.3.5.

With regards to capital payment period, the typical results registered are 134.8 months and -72.5 months for the conventional and advanced meters respectively. For the conventional meter, based on the scale in Table 4-21 show that the value is registered as a good score. This is because capital invested will be returned in 134.8 months (11.23 years) after implementation within the average lifespan of the installed meters. For the advanced meters, the result is registered as very bad as no capital invested will be regained.

The effective surplus is the average monthly surplus collected over the service life of each proposed metering scheme. For this key, a positive value would register as a very good score and a negative value as a very bad score. With the conventional meters, the typical effective surplus has a value of R 3,438.11. This result therefore registers a very good score. As for advanced meters, the effective surplus -R 208,259.25. This shows that the typical advanced metering scheme is too costly to operate.



Table 4-34: Economic results for a typical high income area

4. ECONOMIC					
No	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R845,937.00	R801,414.00	R694,558.80
4.2	Billed unmetered consumption	(/month)	R0.00	R0.00	R0.00
4.3	Total income	(/month)	R845,937.00	R801,414.00	R694,558.80
4.4	Unit income	(/property/month)	R422.97	R400.71	R347.28
4.5	Increased income	(/month)		-R44,523.00	-R151,378.20
4.6	Fractional increased income	(%)		-5%	-18%
Capital cost					
4.7	Water meters	(R)	R 0.00	R 582,000.00	R 3,880,000.00
4.8	Installation	(R)	R 0.00	R 1,261,000.00	R 3,880,000.00
4.9	Communication infrastructure cost	(R)	R 0.00	R 0.00	R 1,500,000.00
4.10	Payment infrastructure cost	(R)	R 0.00	R 0.00	R 150,000.00
4.11	Total capital cost	(R)	R 0.00	R 1,843,000.00	R 9,410,000.00
4.12	Unit capital cost	(R/property)	R 0.00	R 950.00	R 4,850.52
Operational cost					
4.13	Water production	(/month)	R 583,800.00	R 525,600.00	R 455,760.00
4.14	Meter reading	(/month)	R 7,760.00	R 7,760.00	R 9,700.00
4.15	Meter operation & maintenance	(/month)	R 16,160.20	R 16,160.20	R 48,500.00
4.16	Billing cost	(/month)	R 19,400.00	R 19,400.00	R 485.00
4.17	Additional billing system operating cost	(/month)		R 0.00	R 0.00
4.18	Additional communication system operating costs	(/month)			R 0.00
4.19	Failed meter replacement cost	(/month)	R 11,518.75	R 11,518.75	R 97,000.00
4.20	Battery replacement cost	(/month)			R 5,658.33
4.21	Total operating cost	(/month)	R 638,638.95	R 580,438.95	R 617,103.33
4.22	Unit operating cost	(/property/month)	R 329.20	R 299.20	R 318.09
4.23	Decreased operating cost	(/month)		R58,200.00	R 21,535.62
Summary					
4.24	Operational surplus	(/month)	R 207,298.05	R 220,975.05	R 77,455.47
4.25	Increased operational surplus	(/month)		R 13,677.00	-R 129,842.58
4.26	Capital payment period	(months)		134.8	-72.5
4.27	Expected service life	(years)		15	10
4.28	Effective surplus			R 3,438.11	-R 208,259.25

These typical results for the key results are then used as baselines for the subsequent sensitivity analysis chapter. Changes to each key result induced by changes to each individual input parameter will be noted to assess which input has the biggest influence on these results.



5 SENSITIVITY ANALYSIS

5.1 Introduction

During and upon implementation of a metering scheme, the variation in input parameter values influence the outcomes generated. While not all input parameters have a significant impact, there are some input parameters that could prove to be very crucial to the success or failure of implementing and running a metering scheme. To determine which parameters are vital, the extent and significance of the impact by each parameter will need to be quantified. This is done using sensitivity analysis procedures.

Sensitivity analysis is defined as the investigation of a model's potential changes and their impacts on the conclusion drawn from them (Pannell, 1997). Though literature indicates that there are numerous methods and procedures of conducting sensitivity analysis, a simple process was preferred for this research where all but one input parameters were kept constant and the one parameter was varied across its selected low, typical, and high value presented in chapter 5.3.2. The output generated from the typical value was then used as reference for changes induced by low and high values of each parameter.

There are four key outcomes that were selected to govern the success of a metering scheme. Changes to the input parameters resulted in changes to these key outcomes which were then noted and analysed. The four key framework outcomes are as follows:

- Capital payment period
- Effective surplus
- Number of batteries disposed
- Reduction in consumption

The effects of the input parameters on each key outcome are elaborated based on the magnitude of the impact and the correlation of the changes as they vary from low to high value

The magnitude of the impacts of the input parameters are categorised as follows:

- *Non-influential* – parameters where changes in value lead to little or no changes in outcome.
- *Semi-influential* – parameters where changes in value results to moderate change in outcome.



- *Significantly influential* – parameters where changes in value result to the highest and crucial changes in outcome.

For each metering option, a scale is used to group each input parameter with each category ranked by magnitude of impact. For each category, the parameters are ranked in descending order of magnitude. This means the parameter with the largest magnitude impact would be the top entry for each category.

Sensitivity analysis approach cannot be used to conclude the best or optimum approach for implementation. This is because only one parameter is changed at a time and for each parameter change, no optimum result is obtained. However, the sensitivity analysis approach helps identify the crucial and key parameters to monitor upon implementation.

Therefore, this section serves to discuss the results of the sensitivity analysis performed on the input parameters.

5.2 Capital payment period

This is a check to gauge how each input parameter affects the capital payment period of each of their respective proposed metering option.

For this outcome, a positive value would indicate that the capital invested in the proposed metering scheme can be retained after a certain time-period. A negative value would indicate the capital invested would never be regained. A low positive value would be the ideal result as it would entail that the metering scheme would pay off the invested capital early in its service life and begin to generate profits.

5.2.1 Conventional metering scheme

For the conventional metering scheme, Figure 5-1 illustrates the capital payment period outcome. The typical capital payment outcome is 134.7 months (approximately 11.2 years) with the outcome ranging from -738.3 months (-61.5 years) to 462.7 months (38.6 years).

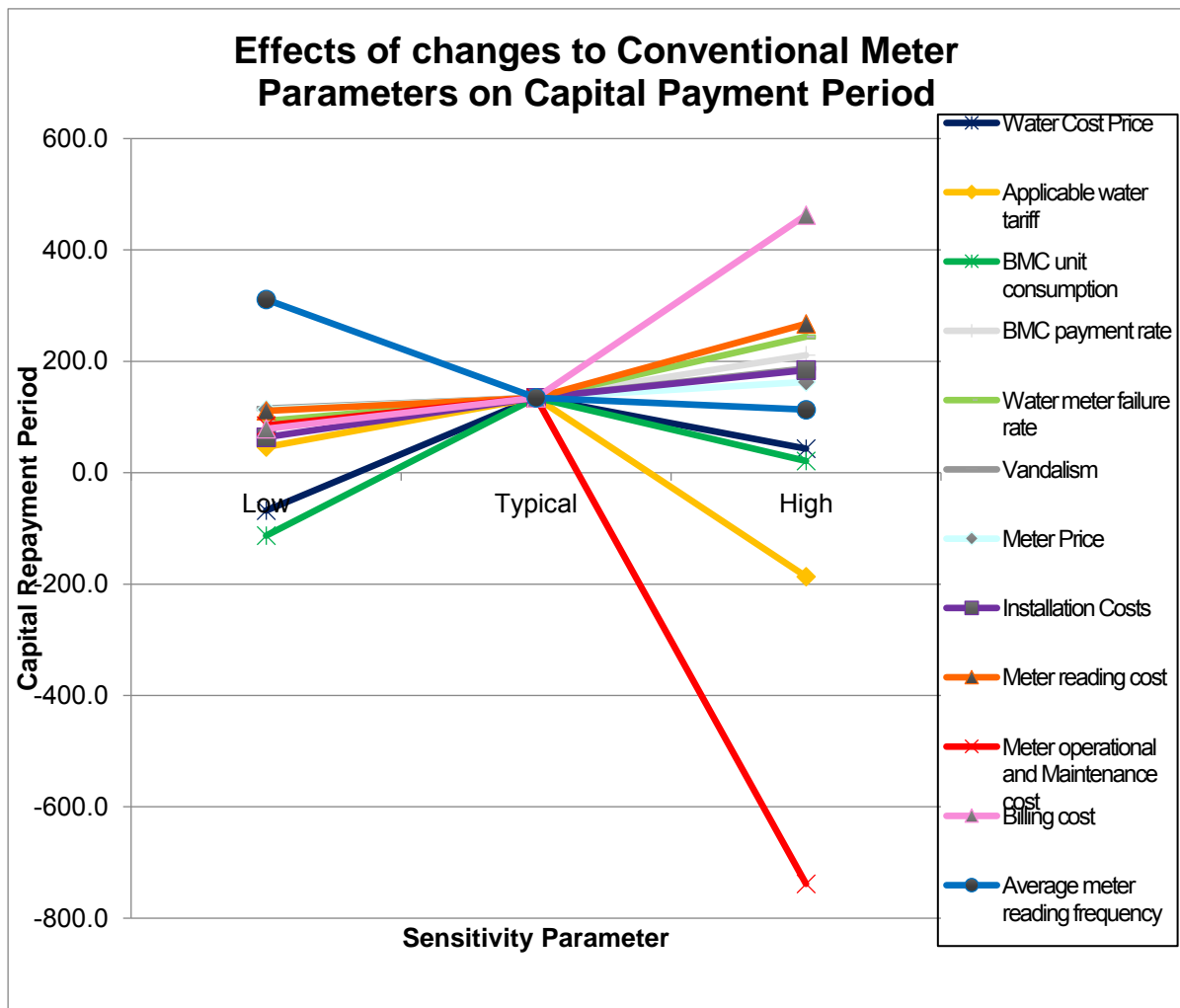


Figure 5-1: Effects of conventional meter input parameters on capital payment period

Upon first observation of Figure 5-1, it can be noted that aside from 4 outcomes (11% of the total outcomes generated), all other outcomes generated are positive values. This illustrates that in most circumstances, capital invested in conventional metering scheme will be regained.

Table 5-1 illustrates the categories of the effects of input parameters for advanced meters. The scale below was used to classify the effects of each metering option.

- ◆ Non-influential: $x < 50$ months
- ◆ Semi-influential: $50 \leq x < 200$ months
- ◆ Significantly influential: $x \geq 200$ months

Where: “x” denotes the modulus difference between the typical value outcome and the range ends outcome.



Table 5-1: Classification of conventional input parameters based on their magnitude effects on capital payment period

Non-influential		Semi-influential		Significantly-influential	
Parameter	x (months)	Parameter	x (months)	Parameter	x (months)
Meter price	28.2	Average time of meter reading	176.7	Meter O&M cost	871.2
Number of properties	0.0	Meter reading cost	132.6	Billing cost	328.6
BMC properties	0.0	Water meter failure	109.8	Applicable water tariff	321.1
Illegal & unbilled connections	0.0	BMC payment rate	76.2	BMC unit consumption	247.9
On-site leakage	0.0	Installation cost	71.0	Water cost price	202.9
Meter service life	0.0	Vandalism	52.4		
Effective service life	0.0				

Based on Figure 5-1, *meter operational and maintenance cost* has the most significant impact followed by *billing cost*. Their respective low value outcomes are 84.7 months and 78.8 months and their respective high value outcomes are -738.3 months and 462.7 months.

As is illustrated in Figure 5-1 and Table 5-1, operating and running costs and income parameters prove to have the most significant impact on the capital payment period for conventional meters. Capital costs such as *meter price* and *installation costs* are not major contributors to the capital payment period.

This could be due to two causes; low capital costs due to the existing infrastructure for conventional metering and the longevity of operating costs and income collected in comparison to capital costs.

Therefore, for conventional meters, operational and running cost and income parameters prove to have the most significant magnitude impact on the capital payment period. This is especially true for *meter operational and maintenance cost parameter* as well as *billing cost* as these two parameters had the highest impact respectively.

Though this outcome serves to gauge the time taken to repay capital invested, capital cost parameters do not directly play a significant role to the capital payment period. Changes to its parameters produce little to no changes in capital payment period

5.2.2 Advanced metering scheme

For the advanced metering scheme, Figure 5-2 below illustrates the capital payment period outcome. The typical value was registered as -72.5 months (-6.0 years) with a range from -230.7 months (-19.2 years) to -42.9 months (-3.6 years).

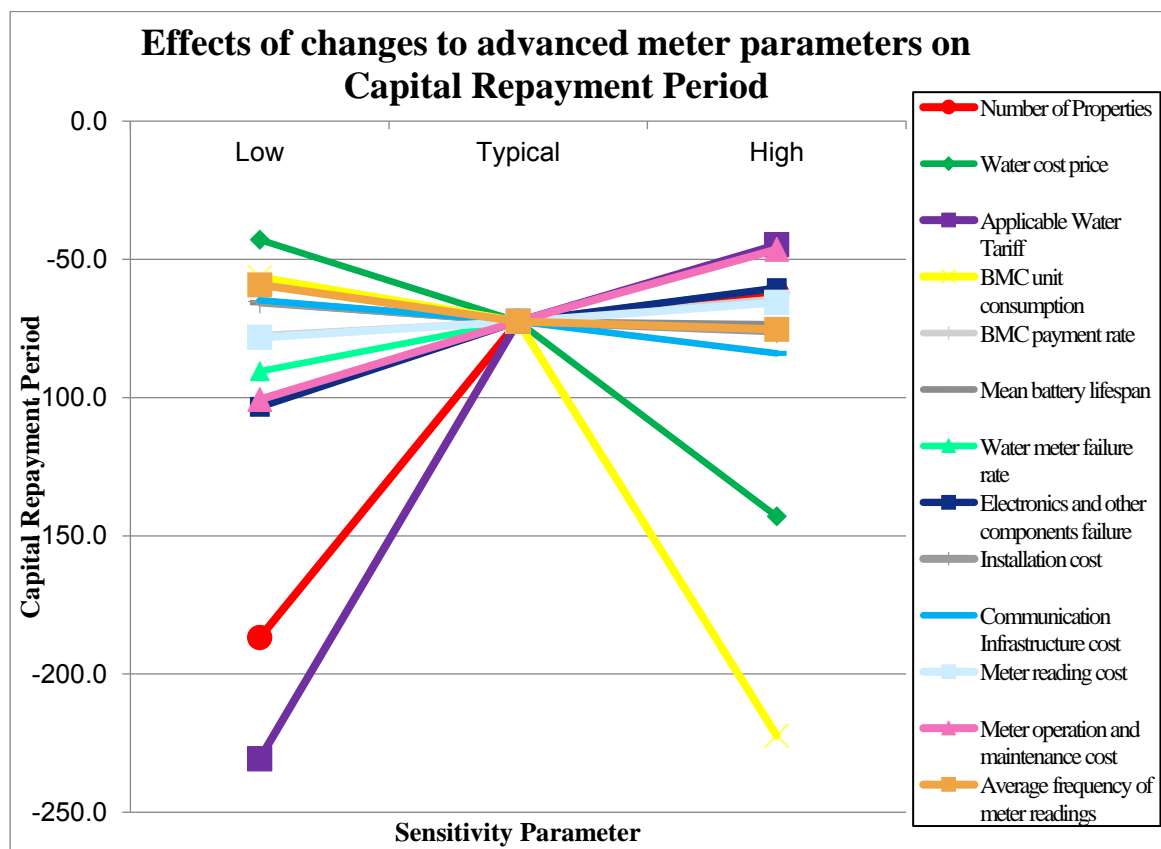


Figure 5-2: Effects of advanced meter input parameters on capital payment period

The first observation noted from Figure 5-2 is that all outcomes generated are negative values. This alludes that for advanced metering schemes, the capital invested will not be returned and hence implementing advanced water metering system in high income areas in South Africa is not feasible.

However, in order to conduct an adequate sensitivity analysis, the typical capital payment period had to be raised. This was done by raising the typical water cost price from R10/kl to R30/kl.

Figure 5-3 illustrates the change in capital payment period induced by changes to advanced metering input parameter value. The typical capital payment period is 74.5 months

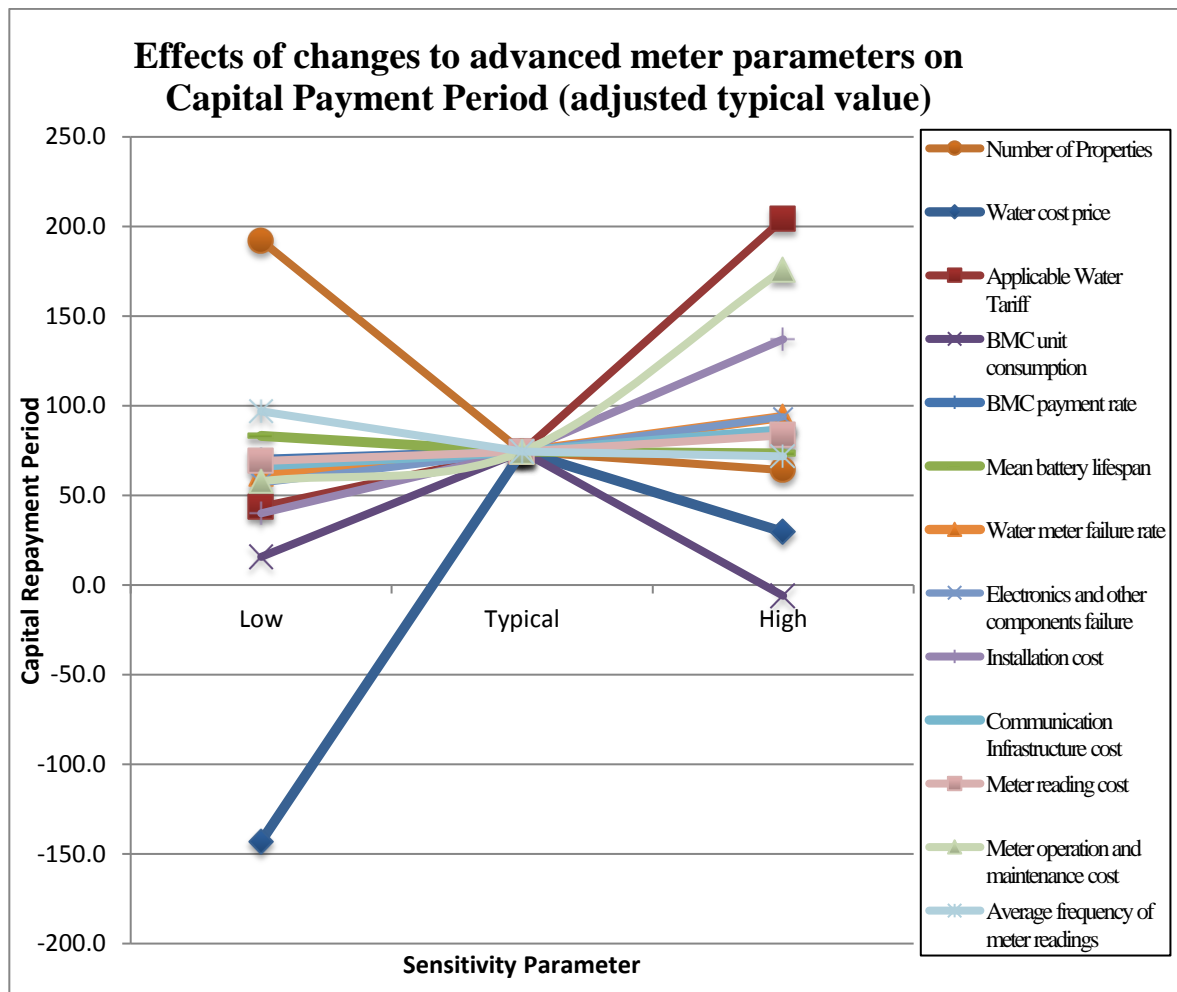


Figure 5-3: Effects of advanced meter input parameters on capital payment period (adjusted typical value)

Table 5-2 below illustrates the categories of the effects of input parameters for advanced meters. The scales used to classify the effects of each metering option were as follows:

- ◆ Non-influential: $x < 10$ months
- ◆ Semi-influential: $10 \leq x < 100$ months
- ◆ Significantly influential: $x \geq 100$ months

Where: “ x ” denotes the modulus difference between the typical value outcome and the range ends outcome.

**Table 5-2: Classification of input parameters based on their magnitude effects on capital payment period**

Non-influential		Semi-influential		Significantly-influential	
<i>Parameter</i>	<i>x</i> (months)	<i>Parameter</i>	<i>x</i> (months)	<i>Parameter</i>	<i>x</i> (months)
Communication infrastructure cost	11.9	BMC unit consumption	80.5	Water cost price	217.5
BMC payment rate	11.5	Installation cost	62.6	Meter price	210.2
Meter reading cost	9.0	Average time of meter reading	22.4	Applicable tariff	129.6
Mean battery lifespan	8.7	Water meter failure rate	19.3	Number of properties	117.5
Vandalism	4.1	Electronics and other components failure	19.3	Meter O&M	101.4
Battery replacement cost	1.5				
Payment infrastructure cost	1.2				
BMC properties	1.1				
Billing cost	0.6				
Illegal or unbilled connections	0.0				
On-site leakage	0.0				
Meter service life	0.0				
Effective service life	0.0				

Based on Figure 5-3 and Table 5-2, *water cost price* has the most significant impact on the capital payment period for advanced meters followed by the *meter price*. Their low values generate a capital payment period of -143.0 months and 40.0 months respectively where as their high values result in a capital payment period of 29.6 months and 284.7 months respectively.

For advanced metering, the high capital costs such as *communication and payment replacement costs* are not influential. However, *meter price and installation cost* are influential.

Meter service life, on-site leakage and illegal connections have no effect on the capital payment period for advanced meters.

5.3 Effective surplus

This is a check to access how each input parameter affects the effective surplus in each of their respective proposed metering option.

Similar to capital payment period, input parameters are grouped based on the magnitude and correlation effects on the effective surplus. Effective surplus is used quantify the amount of

monthly profits accumulated by each proposed option with a different service life. As such, the ideal outcome would be high positive values as negative values suggests that the metering scheme is running on a loss in compared to the current system.

5.3.1 Conventional metering scheme

Figure 5-4 illustrates the effective surplus outcome for conventional meters. The typical outcome is R 3,438.11/month with a range from -R 37,301.89/month to R 77,061.11/month.

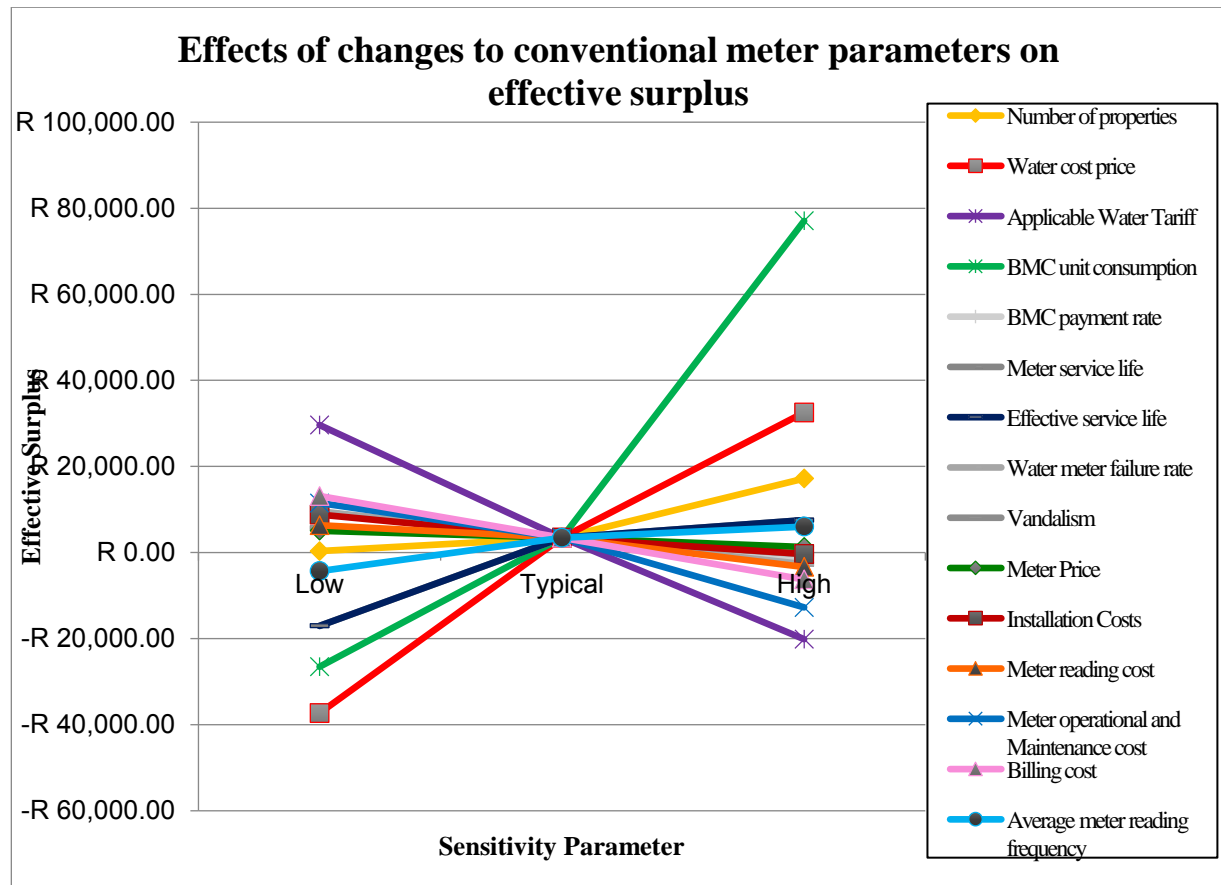


Figure 5-4: Effects of conventional meter input parameters on effective surplus

As illustrated in Figure 5-4, the conventional metering scheme doesn't always generates more profits compared to the current system. Of the total outcomes of end values calculated, 36% are losses.

Table 5-3 illustrates the categories of the effects of input parameters for advanced meters. The scale below was used to classify the effects of each metering option.

- ◆ Non-influential: $x < \text{R } 1000/\text{month}$



- ◆ *Semi-influential*: $R\ 1000/\text{month} \leq x < R\ 15\ 000/\text{month}$
- ◆ *Significantly influential*: $x \geq R\ 15\ 000/\text{month}$

Where: “ x ” denotes the modulus difference between the typical value outcome and the range ends outcome.

Table 5-3: Classification of input conventional meter parameters based on their magnitude effects on effective surplus

Non-influential		Semi-influential		Significantly-influential	
<i>Parameter</i>	<i>x</i> (R/month)	<i>Parameter</i>	<i>x</i> (R/month)	<i>Parameter</i>	<i>x</i> (R/month)
BMC properties	248	No. of properties	13,752	BMC unit consumption	73,623
Illegal or unbilled	0	Billing cost	9,700	Water cost price	40,740
On-site leakage	0	Average time of meter reading	7,760	Applicable water tariff	26,197
		Meter reading cost	6,790	Meter service life	20,478
		Water meter failure	6,143	Effective service life	20,478
		Installation cost	5,389	Meter O & M cost	16,180
		BMC payment rate	4,947		
		Vandalism	3,840		
		Meter price	2,156		

In reference to Figure 5-4 and Table 5-3, *BMC unit consumption* and *water cost price* proof to have the most significant impact on the effective surplus for conventional meters. They have an outcome ranges of -R 26,534.89/month to R 77,061.11/month and -R 37,301.89/month to R32,538.11/month respectively.

System parameters such as *applicable water tariff* and *water cost price*, have the most significant effects on effective surplus. This is followed by operational and running cost parameters such as *meter O&M cost*. Capital cost do not appear to have a directly significant influence on the effective surplus.

5.3.2 Advanced metering scheme

Figure 5-5 illustrates the effective surplus outcome for the advanced meters. The typical outcome is -R 208,259.25/month with a range from -R 986,296.25/month to -R 33,200.28/months

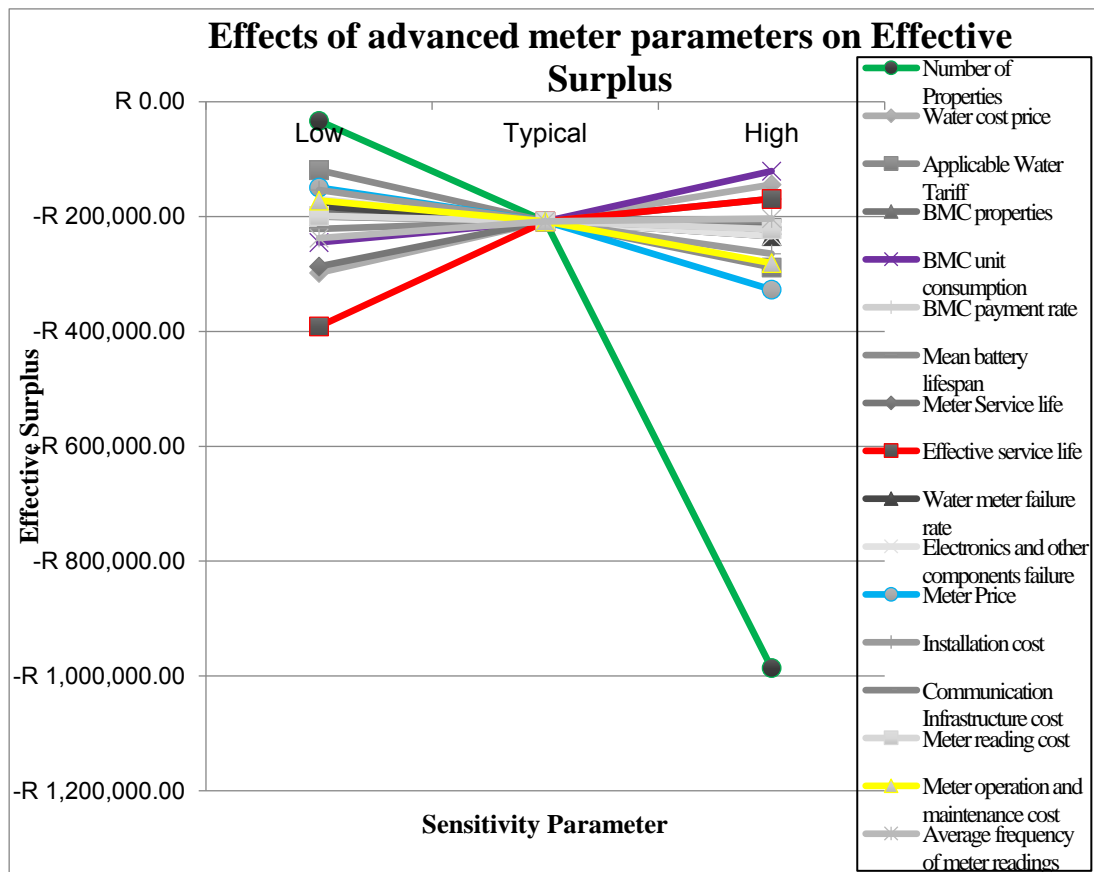


Figure 5-5: Effects of advanced meter input parameters on effective surplus

Like capital payment period, effective surplus for all advanced metering input parameters generate a negative value. This illustrates that advanced metering is currently not economically feasible for high income areas in South Africa.

To carry out the sensitivity analysis, the typical water cost price was again elevated to R30/kl to R15/kl. Figure 5-6 illustrates the sensitivity analysis of the effective surplus. The typical effective surplus is R 47,820.75/month

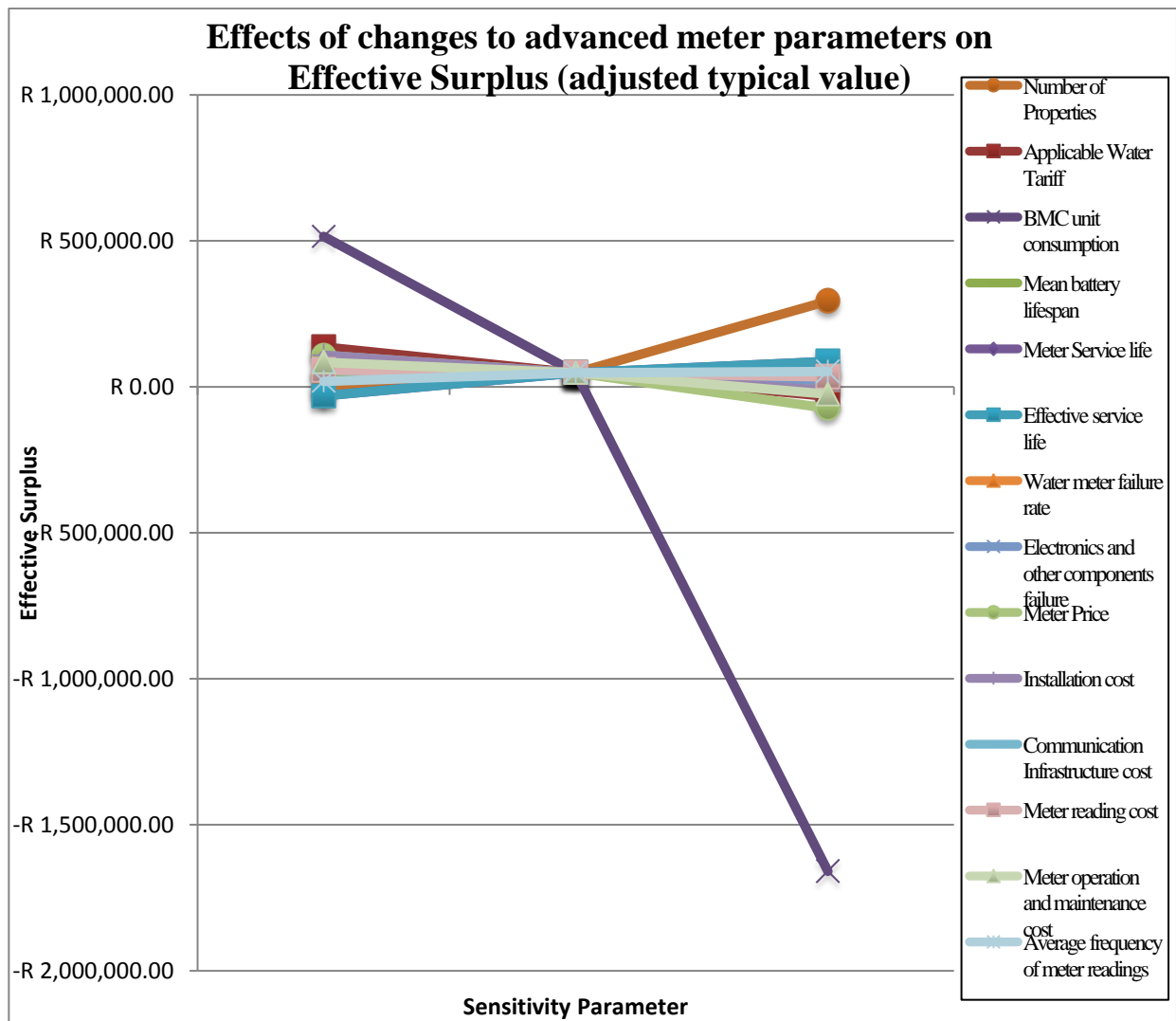


Figure 5-6: Effects of advanced meter input parameters on effective surplus (adjusted typical value)

From Figure 5-6, it can be noted that the advanced metering scheme does not generate surplus despite the parameter value changes. Despite this, Table 5-4 is used to illustrate the categories of the effects of input parameters for the advanced meters. The following scale was used to classify the effects of each parameter.

- ◆ Non-influential: $x < \text{R } 10\,000/\text{month}$
- ◆ Semi-influential: $\text{R } 10\,000/\text{month} \leq x < \text{R } 100\,000/\text{month}$
- ◆ Significantly influential: $x \geq \text{R } 100\,000/\text{month}$

Where: “ x ” denotes the modulus difference between the typical value outcome and the range ends outcome.

**Table 5-4: Classification of input advanced meter parameters based on their magnitude effects on effective surplus**

Non-influential		Semi-influential		Significantly-influential	
Parameter	<i>x</i> (R/month)	Parameter	<i>x</i> (R/month)	Parameter	<i>x</i> (R/month)
Vandalism	6,467	Applicable water tariff	89,046.0	BMC unit consumption	1,706,802.30
Battery replacement cost	2,425	Meter service life	78,416.7	No. of properties	246,283.0
Payment infrastructure cost	1,250	Effective service life	78,416.7	Water cost price	192,060.0
Billing cost	970	Meter O&M	72,750.0	Meter price	121,250.0
Illegal or unbilled	0	Installation cost	60,625.0		
On-site leakage	0	Electronic and other components failure	38,800		
		Average time of meter reading	29,100.0		
		Water meter failure	25,866.7		
		BMC payment rate	16,819.8		
		Meter reading cost	13,580.0		
		Mean battery life span	13,202.8		
		Communication and infrastructure cost	12,500.0		

BMC unit consumption proves to be the most influential parameter with a value outcome range of R515, 515.95/month to -R 1,658,981.55/month. System parameters such as *water cost price* and *number of properties*, prove to have the significant impact. Like capital payment period, high capital cost are not as directly influential as *meter price and installation cost*.

Despite, the large impact induced by *number of properties*, *BMC payment rate* results to a very small change. This is due to small value range assumed for high income areas.

However, as all the outcomes generated are negative, this leads to the conclusion that advanced meters would result to losses generated if implemented regardless of the changes made.

5.4 Number of batteries disposed

This outcome is used to gauge the environmental friendliness of advanced meters. As batteries contain chemicals that could be dangerous to the environment, it's vital to access how advanced meter input parameters affect the number of meter batteries disposed.

Figure 5-7 displays the effects parameters have on number of batteries disposed with the typical outcome as 194 batteries with a range from 19 batteries to 970 batteries.

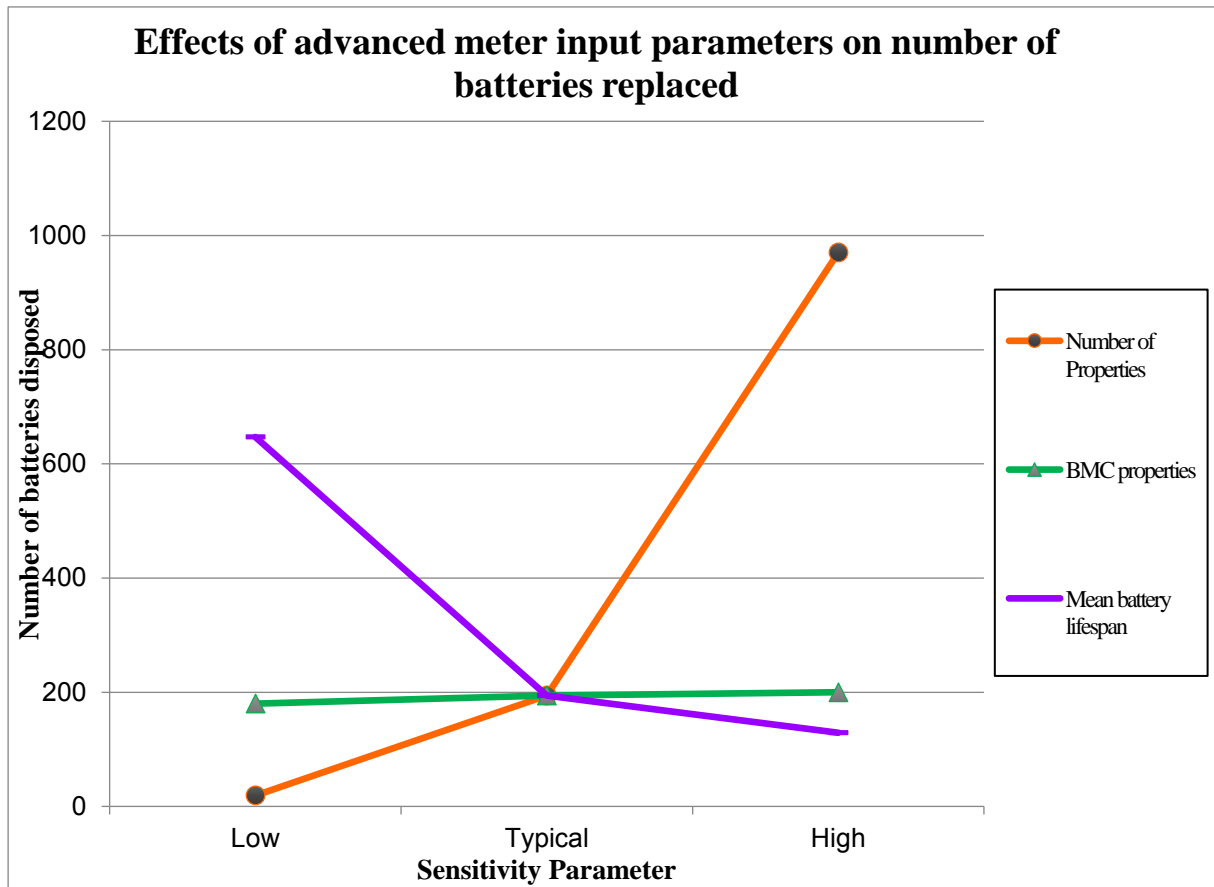


Figure 5-7: Effects of input parameters on number of batteries disposed

As is shown only number of properties, BMC properties and mean battery lifespan affect the number of batteries disposed.

Number of properties is noted to have the biggest impact on this outcome with a range from 19 batteries to 970 batteries. This is followed by *mean battery lifespan* and *BMC properties*. Both *number of properties* and *BMC properties* illustrate a direct correlation which means that increase in parameter value results in an increase in number of batteries disposed. *Mean battery lifespan* shows that increase in parameter value results in reduction in batteries disposed.

From an environmental viewpoint, a metering scheme should ideally reduce the number of meters disposed. Based on the ranking illustrated in Table 4-19, the typical value produces a neutral score with regards to the effects of the number of batteries disposed. Figure 5-7 illustrates that a higher battery life exceeding the typical life span of 10 years and a lower number of

properties in the study area (less than the typical value of 1000 properties) will produce the desired results. However, it's worth noting that *number of properties* has a significant effect on the economic key outcomes. This relationship will be further discussed in the final sub sections of this chapter.

5.5 Fractional reduction in consumptions

Akin to number of batteries disposed, reduction in consumptions is another check to gauge the economic friendliness of both proposed metering schemes.

Currently, throughout the world and more so in Africa, water scarcity is becoming an increasing issue. This means that clean water is becoming more of a crucial commodity. As such preservation and proper conservation is vital. This outcome therefore serves to check how each input parameters of the proposed schemes affect the amount of water conserved as compared to the current systems.

Figure 5-8 and 5-9 display how changes to proposed input parameter results in more conservation of water in comparison to the current system. The typical outcomes for Figure 5-8 and 5-9 were 2 910 kl/month and 9 894 kl/month with ranges from 0 kl/month to 5 820 kl/month and 989 kl/month to 49 470 kl/month respectively

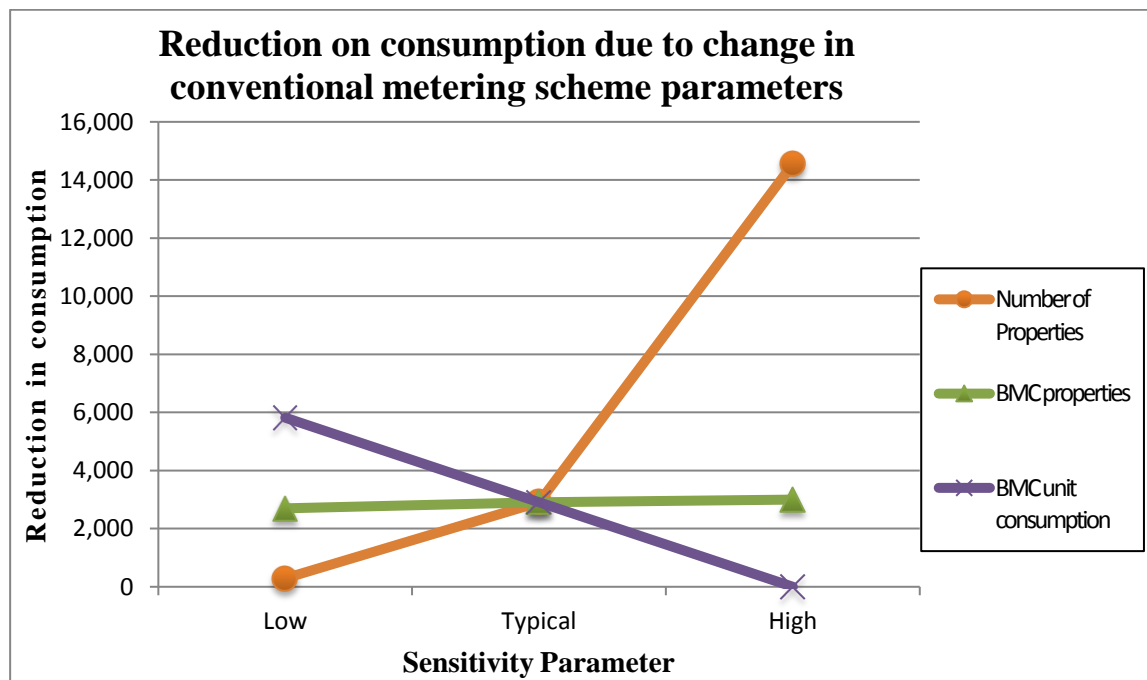


Figure 5-8: Effects of conventional input parameters on fraction reduction in consumption

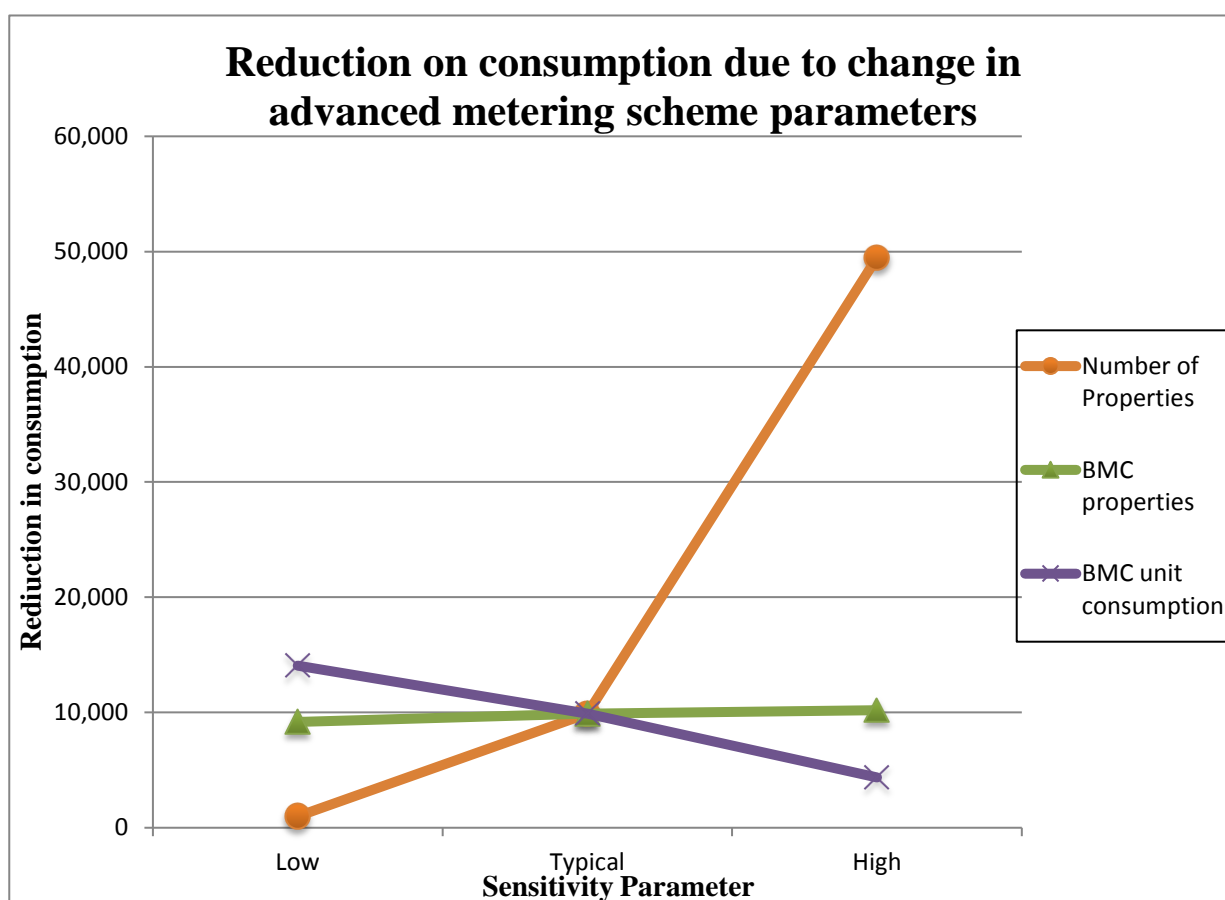


Figure 5-9: Effects of advanced input parameters on fraction reduction in consumption

Both metering schemes are projected to induce similar changes in consumption with reduction in both figures changing by the same percentage. However, the reduction induced by advanced meters is higher than that of conventional meters.

As observed in both figures, only *number of properties*, *BMC properties* and *BMC unit consumption* influence the reduction in consumption. For both schemes, *number of properties* has the largest impact showing a range of 291 kl/month to 14 550 kl/month and 989 kl/month to 49 470 kl/month for conventional and advanced meters respectively.

Only BMC unit consumption illustrates an inverse correlation relationship. This depicts that an increase in value results in a decrease in fractional reduction in consumption and ultimately reduction in water conserved. The reverse is true for direct correlation where increase in value results in increase in reduction in consumption. As such, the ideal case would be high values of direct correlation parameters especially number of properties.



5.6 Analysis summary

In summation of the analysis conducted the following results are noted.

For capital payment period, the following conclusions can be drawn

- For conventional meters, capital invested was returned except for 4 outcomes (11% of total outcomes generated)
- *Meter O&M cost* has the most significant impact for conventional meters. Other parameters with significant impact are *billing cost*, *applicable water tariff*, *BMC unit consumption* and *water cost price*.
- For advanced meters, capital invested will not be regained irrespective of parameter changes for the ranges indicated
- However, when adjusted for sensitivity analysis, *water cost price* followed by *meter price* proved to be the most influential on capital payment period
- Capital cost parameters, except for *installation cost* and *meter price*, did not have a significant direct effect on capital payment period for both proposed schemes
- Conventional metering scheme is the preferred option of the two proposed metering schemes for adequate invested capital returns.

For effective surplus, the following conclusions can be drawn:

- For all parameters, advanced metering scheme doesn't produce a positive effective surplus.
- For conventional meters, 64% of the calculated outcomes are surplus
- For conventional meters, *BMC unit consumption* proves to have the biggest impact on effective surplus whereas for advanced meters, *number of properties* proves to be the most crucial parameter.
- For advanced meters, *BMC unit consumption* and *number of properties* prove to be the most influential. These are followed by *water cost price* and *meter price*
- For both schemes, capital cost have a semi to none influential effect on effective surplus with the exception of *the meter price* for advanced meters
- Conventional metering scheme is the preferred option for adequate effective surplus

With regards to number of batteries replaced, the following conclusions are drawn:

- This parameter only affects advanced meters as conventional meters do not contain batteries



- This parameter is affected by *number of properties, BMC properties and mean battery lifespan*. Number of properties has the biggest influence on the outcome
- The ideal situation is a reduction in number of properties or increase in battery lifespan

Regarding the fractional reduction in consumption, the following conclusions are drawn:

- Both metering scheme produced percentage increase with advanced meters having a magnitude change
- This parameter is affected by *number of properties, BMC properties and BMC unit consumption*. Number of properties has the biggest influence on the outcome
- The ideal situation is an increase in the number of properties.



6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study aimed to investigate the feasibility of implementing an advanced metering technology in high income areas in South Africa. To achieve this objective, an evaluation framework was developed to gauge the performance of an advanced metering system based on four key criteria; technical, economic, environmental, and social.

Furthermore, sensitivity analysis was conducted to access which input parameters would proof to be crucial to the success or failure of implementing either an advanced or new conventional metering system. The following conclusions can be drawn from the results obtained and analysis conducted

6.1.1 The economic viability of proposed metering systems

Advanced meters are not economically viable in high income areas in South Africa. Effective surplus and capital payment period were used as economic indicators. On both these outcomes, advanced metering systems registered negative results across the parameter ranges. Possible reasons for these outcomes are the lack of existing infrastructure as well as high initial capital costs and high operating costs. These results in capital invested not returned and a reduction in profits generated when compared to current metering system.

With regards to implementing new conventional metering system, increase in metered properties as well as installation of new conventional meters, thus reduction in meter under registration and detection of leakage in the location of old meters, could proof to be more economically beneficial.

Income collected from consumption of utilities (water, electricity etc.) serve as one of the main income sources for municipalities. Reduction in income collected as well as debt incurred will hamper the municipalities' ability to maintain, operated these serves as well as replace necessary infrastructure.

6.1.2 The environmental viability of proposed metering systems

Due to leakage detection capabilities and more immediate consumption feedback, thus more conservative and monitored consumption, implementation of advanced meters results in higher reduction in consumption as compared to both current and new conventional metering systems.

However, the added variable of disposing faulty meter batteries as well as battery failure on site alludes to consideration that advanced meters are not environmentally compatible. Feasible



advanced metering technology need batteries with lifespans exceeding 10 years. Well placed battery disposal procedures will be required for environmental viability.

6.1.3 The impact of high capital parameters on the economic output

Changes to high capital parameters, such as communication infrastructure cost, do not have a direct impact on the economic output. Other capital costs such as meter price and installation price have a more direct and significant.

This is because high capital costs are a once off price. Meter price and installation cost are incurred when a meter fails or reached its lifespan.

6.1.4 Miscellaneous

With regards to environmental output, number of properties, BMC properties and BMC unit consumption are the only input parameters that have an effect for both advanced and conventional metering systems

The technical assessment of a proposed meter is simply a check to access whether the selected meter abides by the SAB metrological standards put in place.

Social factors are considered negligible for high income areas as literature documents that hostility to the implementation of new water meters arises when a community with low to middle income level. Implementing a new meter that aims to reduce consumption may lead the community to feel like their rights to water are infringed. As consumers in high income areas are able to pay for their usage, such reactions would not be expected

6.2 Recommendation

One significant challenge and limitation faced throughout this research was the lack of South African literature and field data on advanced metering implementation (except for prepaid meters) especially in high income areas. Case studies and literature on the implementation of advanced meters in developed countries were used as proxies for this research. This meant that input data obtained from these areas could vary from what would be found in South Africa. For example, capital costs, such as communication infrastructure obtained from literature of developed regions, are based on the market price of those countries which may vary from the costs found in South Africa.

Data was also acquired from a vast array of developed regions (USA, Italy, Australia etc.) with different conditions. This limited the homogeneity of the data obtained. As such, a lot of assumptions and estimations were made for numerous variables.



Therefore, the following recommendations are made for more refined and region specific research:

- i. Numerous high income study areas in South Africa can be used where one area has installed advanced meters and another area has conventional meters. A control can be used where new conventional meters are installed in an independent area. Data required can be noted prior to monitoring and at set intervals to note the changes made. For this to be fair, the regions selected should be of a similar income and consumption level and there shouldn't be a great disparity in sizes
- ii. Explore whether more refined and efficient data collection and management techniques and approaches on current metering system would reduce water loss and consumption without the need for communication capabilities.
- iii. Assess the effects of implementation of a small scale, low capital AMR. In this study, the only added capability to the meter would be communication capabilities.
- iv. Investigate the impact of implementing both advanced water and electrical metering system. This study would look whether capital and operational cost shared for both services could make advanced metering more economically feasible
- v. Using data from South African case studies, improve the evaluation framework to better simulate the real conditions. This would also include addition of income parameters such as income arising from government budget



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Appendices



A PRODUCTS

A.1 Introduction

With the increased awareness of a potential need for advanced meters, various manufacturing companies have released a variety of metering products and solutions onto the market. This chapter illustrates the array of water meters currently available and also describes the supporting infrastructure and software systems needed to set up a water metering system. Notable case studies from each manufacturer will be presented to provide an overview of the application of the product as well as the feedback given by users.

A.2 Elster Metering

A.2.1 Introduction

Company Background

Elster Metering is an internationally acknowledged industrial company known for its development of metering tools and software that are used to measure and improve the flow of natural gas, water and electricity.

Elster Metering was founded in New York as a gas metering company in 1836, initially known as Elster American Meter. In 1848, the company founded its first international division in Berlin and has since grown to a multinational group, known as the Elster Group. The South African branch of Elster Metering is known as Elster Kent.

Product ranges

Elster Metering manufactures and retails an array of water meters. Elster Metering produces different types of conventional meters such as single-jet meters, multi-jet meters, volumetric meters and bulk meters. Elster Metering also provides meters, supporting infrastructure and software packages that can be used to set up an advanced water metering system (either AMI or AMR).

A.2.2 Water meters

Single-jet meters

Elster supplies three single-jet meter models capable of being used as advanced meters. A summary of the properties of these meters is given in Table 6-1 below.

Elster S110 meter

The S110 is a single-jet dry rotor meter that is mostly adopted in Europe but can also be used outside Europe. The S110 is a surface mounted meter intended for residential use. It conforms to the ISO 4064 Class B for horizontal installation and Class A for vertical installation as illustrated in Table 6-1.

The S110 Hybrid and the S110 type IO have the potential for advanced metering. The S110 Hybrid is fitted with an electronic counter and impeller scanning capabilities. These meters are available in sizes 15mm and 20mm, with nominal flow rates (Q_3) 2.5m³/h and 4m³/h respectively as illustrated in Table 6-1.



Figure 6-1: a) S110 meter b) S110 Hybrid meter (adapted from Elster Metering)

Elster S150 meter

The S150 meter is a single-jet velocity meter intended for residential use. It consists of a dry register meter with 360-degree rotation rollers to ensure easy readability. The register is designed to be resistant against moisture.



Figure 6-2: S150 meter (adapted from Elster Metering)

The S150 has the capacity to be fitted with a bi-directional pulser after installation for remote meter reading. In accordance with international EN14154 standards, the S150 has a high metrological performance up to R160 for horizontal installation and R50 for vertical installation. The S150 is available in 15mm and 20mm sizes. Table 6-1 displays the metrological properties and metering features, capabilities and functionality of the S150.

Elster S220 meter



The S220 is a single-jet velocity meter intended for residential consumers. It is a dry register velocity meter with a 360-degree rotation roller to ensure easy readability. The register is designed to be resistant against moisture and shock.



Figure 6-3: S220 meter (adapted from Elster Metering)

The S220 has the capability to be fitted with a bi-directional pulser on site. This meter is in accordance with the International EN14154 standards.

The S220 is available in sizes 15mm and 20mm; however, only metrological and performance data of the 15mm size could be found from Elster Metering. The properties and data can be found in Table 6-1.



Table 6-1: Elster single-jet meters for advanced metering applications

Description	Symbol	Units	S110			S150				S220
Metrologic Properties										
Meter Sizes	DN	mm	15	20		13/15		20		15
Meter Class	Q ₃ /Q ₁ or Other		R40 B(Horizontal) A(Vertical)			R125	R160	R125	R160	R200
Minimum Flow Rate	Q ₁	l/h	62.5	62.5	100	20	15.625	32	25	12.5
Transitional Flow Rate	Q ₂	l/h	100	100	160	32	25	51.2	40	20
Permanent Flow Rate	Q ₃	m ³ /h	2.5	2.5	4	2.5	2.5	4	4	2.5
Overload Flow Rate	Q ₄	m ³ /h	3.125	3.125	5	3.125	3.125	5	5	3.125
Meter Features and Capabilities										
Built-in valve			No			No				No
Battery			No			No				No
SABS compliant			Not specified			Not specified				Not specified
Other standards meter complies with			ISO 4064			EN 14154-1				UNE EN 14154-1
Any alarm features?			No			No				No
Meter Functionality										
Is it capable of remote communication?			Add-on			Add-on				Add-on
Which communication technology?			M-bus/Radio acquisition and Flex plus radio modules for S110(IO) and S110 Hybrid respectively			Pulse transmitter or integrated radio technology				Pulse transmitter or integrated radio technology
Does it have uni- / bi-directional communication?			AMR uni-directional communication			AMR/AMI bi-directional communication				AMR/AMI bi-directional communication
STS compliance			Not specified			Not specified				Not specified

Electronic meters

Elster supplies three electronic meters' models with capacity to be uses as advanced meters. A summary of the properties of these meters is given in Table 6-2.

Elster V200/V210 Hybrid meter

The SM150 (both SM150E and SM150P) is an advanced meter that utilizes 'solid state' electronic metering technology. The SM150 has no moving parts and uses a unique air detection system to prevent measurements of air flow in the water pipes.

The SM150 has AMR communication capabilities. Along with this ability, this advanced meter is able to detect leaks and lack of flow in the system. Due to these features, this advanced water meter is claimed to have lower lost revenue as compared to conventional meters.

The SM150 is stated to have a 10 year and a 15-year battery life span for the SM150E and SM150P respectively. Both also give a 12-month battery replacement warning.

The SM150 is EN, ISO, MID and OIML approved. In accordance with the ISO 4064, the SM150 is manufactured in class C and D. However, according to international standards, the SM150 meter classes are R160, R200, and R250. The SM150 is available in the G $\frac{3}{4}$ P size thread or the DN 20 equivalent. Table 6-2 displays the metrological properties and meter capabilities of the SM150.



Figure 6-4: SM150 meter (adapted from Elster Metering)

Elster SM250 meter

The Elster SM250 meter is a fluidic oscillator type, cold water advanced meter. It has no moving parts and is therefore unaffected by grit and sand. It uses an air detection system, similar to the SM150, to prevent reading air flow in the system. Through this, the SM250

retains accuracy and the adequate working condition throughout the product lifetime. It is available in a 20mm.

The SM250 has AMR communication capabilities. This means that this meter has the ability to detect leakage and lack of flow in the system. The SM250 is stated to have a battery life span of 15 years under normal operating conditions.

In accordance with international standards, the SM250 has class R160 and R200. Table 6-2 shows the metrological and performance data for the SM250.



Figure 6-5: SM250 meter (adapted from Elster Metering)

Elster SM700 meter

The SM700 fluidic oscillator advanced water meter was designed to address the increasing global need for economic and intelligent metering technology. Like the SM250, the SM700 has no moving parts and as such is unaffected by wear or subsequent accuracy problems caused by particulate matters like grit and sand.

The SM700 has AMR and AMI communication capabilities. With this, the meter can detect tampering, fraud, air and no water flow in the system. Through the AMI features, meter diagnostics can be acquired while the meter is in operation. The SM700 has a removable battery pack with an expected life span of 20 years.

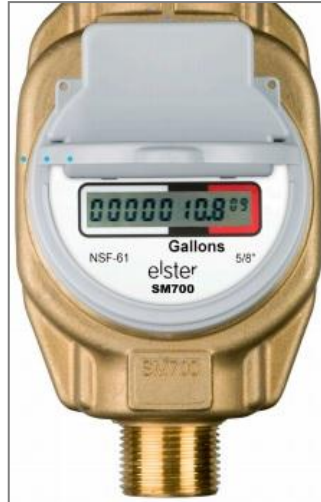


Figure 6-6: SM700 meter (adapted from Elster Metering)

The SM700 is stated to meet the performance requirements of the AWWA C713 standards for fluidic oscillator water meters. The meter is available in sizes ranging from 15mm to 25 mm illustrated in Table 6-2.



Table 6-2: Elster electronic water meters for advanced metering applications

Description	Symbol	Units	SM150			SM250		SM700		
Metrologic Properties										
Meter Sizes	DN	mm	20			20		15	20	25
Meter Class	Q ₃ /Q ₁ or Other		R160	R200	R250	R160	R200	N/A	N/A	R71
			Also Classified as ISO 4064 Class C and D							
Minimum Flow Rate	Q ₁	l/h	15.6	12.5	10	25	20	0.03	0.05	0.08
Transitional Flow Rate	Q ₂	l/h	25	20	16	40	32	0.05	0.11	0.17
Permanent Flow Rate	Q ₃	m ³ /h	2.5			4		n/a	n/a	5.7
Overload Flow Rate	Q ₄	m ³ /h	3.125			5		4.5	6.8	11.4
Meter Features and Capabilities										
Does it have an in-built valve?			No			No		No		
Does it have a battery?			Yes, with a 10- and 15-year life span for the SM150E and SM150P respectively			Yes, with a 15-year life span		Yes with a 20-year life span		
Does it meet SABS requirements?			Not specified			Not specified		Not specified		
Other standards and requirements approved or complied?			ISO 9001, UK Pattern, Australian Pattern and MID approved			OIML R49 approval		AWWA C713		
Any Alarm features?			Has leak, air and no flow detection			Has leak, air and no flow detection		Has leak, air, tamper, fraud and no flow detection		
Meter Functionality										
Is it capable of remote communication?			Built in			Built in		Built In		
Which communication technology?			M-bus, power line carrier or radio acquisition modules			M-bus or radio acquisition modules				



Does it have uni- / bi-directional communication?	AMR communication	AMR communication	AMR/AMI bi-directional communications
STS compliance	Not specified	Not specified	Not specified



Positive displacement meters

Elster V110 meter

The Elster V110 is a volumetric meter with a co-polymer resin manufactured body which allows it to operate where water with aggressive or dezincification properties exists. The V110 is available in sizes 15mm, 20mm and 25mm.



Figure 6-7: V110 meter (adapted from Elster Metering)

In accordance with BS5728 and ISO4064, the V110 has a meter class C. Table 6-3 below displays the performance and metrological data for the V110.

Elster V200/V210 Hybrid meter

The V200/V210 Hybrid is a volumetric water meter with an integrated electronic register and incorporated advanced data features and radio communication. It's known as hybrid as this is a meter that was made by combining flow measurement technology with advanced metering functionality. The V200/V210 hybrid is manufacture in the meter sizes 15mm, 20mm and 25mm.



Figure 6-8: V200/V210 hybrid meter (adapted from Elster Metering)

The V200/V210 Hybrid is European Directive 2004/22/EC, EN 14154, OIML R49 and ISO 4064 approved. Table 6-3 displays the features and capabilities of the V200/V210 Hybrid.



Table 6-3: Elster positive displacement water meters for advanced metering applications

Description	Symbol	Units	V110			V200/V210 Hybrid		
Metrologic Properties								
Meter Sizes	DN	mm	15	20	25	15	20	25
Meter Class	Q ₃ /Q ₁ or other		R100			R400	R400	R400
Minimum Flow Rate	Q ₁	l/h	15	25	35	6.25	10	39.4
Transitional Flow Rate	Q ₂	l/h	22.5	37.5	52.5	10	16	63
Permanent Flow Rate	Q ₃	m ³ /h	1.5	2.5	3.5	2.5	4	6.3
Overload Flow Rate	Q ₄	m ³ /h	3	5	7	3.125	5	7.875
Meter Features and Capabilities								
Does it have an in-built valve?			No			No		
Does it have a battery?			Yes, with a 15-year life span			Yes, with a 10-year life span		
Does it meet SABS requirements?			Not specified			Not specified		
Other standards and requirements?			BS 5728 and ISO 4064 approved			Directive 2004/22/EC, BS EN 14154-1, OIML R49 and ISO 4064 approved		
Any alarm features?			Has leak detection			Has leak, no flow, back flow and low battery detection		
Meter Functionality								
Is it capable of remote communication?			Built in			Built in		
Which communication technology?			M-bus or pulse acquisition modules			One- or two-way radio communication		
Does it have uni- / bi-directional communication?			AMR and AMI bi-directional communication			AMR/AMI bi-directional communication		
STS compliance								

A.2.3 Supporting infrastructure

Introduction

Some conventional meters can be turned into advanced meters when integrated with supporting infrastructure. And advanced meters that lack certain functionalities can be integrated with other infrastructure to meet specific needs. Elster Metering has manufactured an array of such supporting infrastructure that can achieve both. This section will look at some examples.

E-Log meter

The Emeris Log meter, also known as E-Log meter, allows for precise monitoring of the 24-hour consumption measured by a water meter by means of an E-Log data logger and a data collection and visualization software solution. This meter is easy to install and involves no costly IT projects.

The E-Log meter offers an array of options for effective management, control and analysis. The user can easily access metering data and events, from leak warnings or anomalous consumption through to analysis of the correct meter sizing.



Figure 6-9: E-Log meter (adapted from Elster Metering)

The E-Log device is connected to the pulse output of the meter. The E-Log reads the meter periodically and logs the reading values in an internal memory. Periodically the E-Log transmits the logged data to a central data centre. The user can then access all the data through a dedicated, secure web portal. Figure 6-10 demonstrates the operation of an E-log meter. The E-Log can also provide daily maximum and minimum flows as well as alerts such as potential leaks, bursts and low battery level.



Figure 6-10: Illustration of how an E-Log meter works (adapted from Elster Metering)

The features and specifications of an E-log meter are as follows:

- Integrated GPRS modem, 900/1800/1900 MHz
- Lithium battery, 14.5 Ah
- Battery life claimed to be longer than 12 years with monthly transmission (with daily transmission longer than 5 years)
- Built-in e-SIM card, provider-independent

Data Logger DL200W

The Data Logger DL220W is a compact, battery powered device designed to be used for the acquisition and storage of metering pulses and/or level changes for various types of energy. Full details of the product can be obtained from Elster Metering.



Figure 6-11: An example of a DL200W data logger (adapted by Elster Metering)

The DL220W, in combination with the appropriate components, reliably collects and transfers data for evaluation purposes in the fields of gas, electricity, water and district heating consumption.

It is used by tariff customers with varying amounts of consumption and by energy suppliers in substations. The DL220W supports the process of billing for commercial and

industrial customers. The data logging feature provides very detailed information on the customer consumption profile.

The DL2000W features and specifications are as follows:

- 1- or 2-channel mode (for compound meters)
- IP68 protection class
- Integrated GSM-modem for data communication without external energy supply
- SMS function for alarms
- Reusable SIM-card; batteries can be changed
- Battery change by the user
- Battery operation for basic unit; service life depending on operating mode is claimed to be 8 years
- Battery operation for the GSM modem unit; service life depending on operating mode is claimed to be 4 years
- Event-controlled archiving of meter readings.

Wave flow

Wave flow is an advanced battery-powered wireless transceiver and data logger for demanding advanced metering applications. It is a flexible platform that can be integrated into new water meter designs or connected with existing meters as an aftermarket add-on.



Figure 6-12: An illustration of Elster's Wave flow data logger and transmitter (adapted by Elster Metering)

The Wave flow provides remote access to relevant meter information as it logs meter data periodically and transmits data either automatically or on demand. This allows utilities to speed up data collection and billing cycles. Wave flow integrates with Elster's Wavenis wireless technology for large scale automated metering networks as well as walk by collection. Wave flow can also be integrated into gas and electrical meters.

The Wave flow's features and specifications are as follows:

- Radio module bi-directional communication
- Inputs for up to 4 pulse meters
- IP68 protection class
- Battery operated with a stated service life span of 10 years
- Designed for walk-by and advanced metering fixed networks
- Programmable data logging with storage capacity of up to 2100 readings
- Capable of data transfer to and from remote locations.

Falcon Communication Module

The Falcon Communication Module is a robust solid state pulser that forms the base of an AMR/AMI system. This pulser allows for bi-directional communication and can be installed to any Elster meter with a communication interface.

However, as this module acts only as a transmitter and receiver, it needs to be installed in conjunction with a data logger. As such, Elster Metering recommends use of any data logger or their TRC600 radios as they can be used to monitor the water network system.





Figure 6-13: Elster's Falcon Communication Module (adapted by Elster Metering)

The Falcon Communication Module is available in 2 types, the PR6 and PR7. The module complies with the EN 13757 standards.

The features of the Falcon Communication Module are as follows:

- The PR6 and PR7 are bi-directional pulse transmitters for use with data loggers or Elster's TRC600 radios allowing monitoring of the water network system
- When used in a Fixed Network system, backflow alarms will be generated automatically
- Fully self-contained PR6 and PR7 pulsers that do not need external power and are compatible with all major data loggers
- For residential meters, the battery life is designed to last for 12 to 14 years at normal use
- PR6 and PR7 pulsers are both easy and quick to fit to pre-equipped Elster water meters. A simple push fit system is used with residential meters. Both knurled thumbscrews and screws are used for bulk meters
- Tamper evident labels can also be used to monitor attempts to remove the pulse units
- The PR6 and PR7 pulsers are self-contained and do not require external power
- Both PR6 and PR7 have forward and backflow detections
- Robust IP68 design.

Wavenis Technology

Wavenis is a highly optimized wireless technology for M2M (Machine to Machine) and WSN (Wireless Sensors Network) applications. Wavenis offers a host of features to simplify network installation, remote control, data monitoring, and automated 2-way communications.

The Wavenis technology consists of the following features:

- Designed for reliability, power savings, network coexistence, robustness against interference



- Significant range and power advantages over other so-called ultra-low-power wireless technologies
- Worldwide operation in major license-free ISM bands (868, 915 and 433 MHz)
- Ideal for low-traffic, 2-way data & M2M applications from 4.8 to 100 kbps (typically 19.2 kbps)
- Maximized link budget and high receiver sensitivity for reliable long-range communications in difficult environments
- Certified ETS300-220, FCC15-247, 15-249
- Has a data rate range of 4.8kbps to 100 kbps. However, typical values are 9.6 kbps @ 433MHz and 868 MHz and 19.2 kbps @ 915 MHz.



A.3 Sensus

A.3.1 Introduction

Company background

Sensus is an internationally renowned industrial company that is associated with the production and the distribution of metering tools and solutions for gas, electricity and water consumers.

Sensus was founded from a collaboration of two metering companies, National Meter Company and Pittsburgh Equitable Meter Company, founded in 1870 and 1886 respectively, which joined in 1989 to form Sensus Metering Company. In 1997, Sensus merged with the Pollux Meter Group from Europe.

Thereafter, Sensus grew to be recognized as one of the leading companies in the development of metering solution. Currently, Sensus is developing solutions with AMR and AMI capabilities. This section discusses this company's range of advanced water meters and advanced water metering components.

Product ranges

Sensus manufactures and retails numerous arrays of water meters. It produces different types of conventional meters such as single-jet meters, multi-jet meters, volumetric meters and bulk meters. Most of the conventional meters produced by Sensus can be retrofitted to have AMR capabilities due to the High-Resolution Interface (HRI) module. Sensus also provides meters, supporting infrastructures (such as HRI sensors) and software packages that can be used to set up an advanced water metering system (either AMI or AMR).

Meters provided by Sensus are shown to conform to the EEC factory calibration (this is the former European Council Directive) as well as to the Measurement Instrument Directive (MID) calibration. In terms of the EEC standards, water meters have to meet the 75/33/EEC directive (for cold water meters) and 79/830/EEC directive (for hot water meters). However, since 30 October 2006, all new manufactured water meters that measure volumes of cold or heated water to residential, commercial and light industrial areas have to comply with the MID 2004/22/EC standard.

Therefore, this report will state the MID specifications of a product for the purpose of comparing the products by a specific company and between manufacturers. The EEC calibration will also be briefly stated if met by the product.



The South African branch of Sensus states that its products adhere to the ISO 9001; however, it does not indicate which meters meet this standard as most of the product information is aimed at the European market.

A.3.2 Water meters

Single-jet meters

Sensus supplies three single-jet models that can be used as advanced meters. These are the 120 and the 120C meters. A summary of the properties of these meters are given in Table 6-4.

Sensus 120 meter

The 120 is a dry dial single-jet water meter. The 120 is pre-equipped with AMR capabilities through pulse or radio interface.

As it is a dry dial meter, the 120 meter uses magnetic transmission from the measuring chamber to the dry dial, resulting in high resistance to water impurities. The 120 meter has been designed to be shielded from magnetic manipulation and mechanical forces.

Other features of the 120 meter are as follows:

- A non-return valve to prevent the water travelling back through the meter
- High resistance to water impurities
- Insensitive to upstream disruptive elements
- Tamper proof
- 355° swivelling register for easy readability
- A High-Resolution Interface (HRI) module which is a Sensus product that acts as a universal sensor and is compatible with most Sensus meters. As this is a supporting infrastructure, details of the HRI are elaborated further on in the report.

The 120 meter is compliant with the EEC directives 75/33/EEC and 79/830/EEC, and with 2004/22/EC (MID), EN 14154:2007, OIML R49:2006 and ISO 4064:2014 specifications. The metrological class for the 120 meter is R80 and R40 for the horizontal and vertical installation respectively. As indicated earlier, Sensus products are stated to meet the South African ISO 9001 certification.



Figure 6-14: Sensus 120 water meter (adapted from Sensus)

The 120 EEC is available in 15mm and 20mm sizes whereas the 120 MID is available in 15 mm.

Sensus 120C meter

The 120C meter is a dry dial single-jet velocity meter with a 355° swivelling register. As it is a dry dial meters, the 120C uses magnetic transmission to turn the register and record the flowrate through the meter.

The 120C has numerous features and capabilities. These are as follows:

- Can be integrated with a HRI interface module for AMR capabilities through pulse and radio interface
- Tamper proof
- Resistant against aggressive water and high forces
- Environmentally friendly
- Non-return valve.

The 120C conforms to the EEC 75/33/EEC and 79/830/EEC directive, and to 2004/22/EC (MID), EN 14154, OIML R49 and ISO 4064 specifications. The metrological classes for the 120C are R80 and R40 for horizontal and vertical installation respectively.

The 120C is available in 15mm size as reflected in Table 6-4.



Figure 6-15: Sensus 120C water meter (adapted from Sensus)

Sensus 820 meter

The 820 meter is a single-jet velocity meter with a semi dry register. It's designed to produce high accuracy metering of water containing solid particles regardless of installation position.

The 820 comprises of other features and characteristics such as the following:

- Large measuring range
- Noiseless operation
- Capable of being retrofitted with a HRI pulser and through this can have AMR capabilities
- High resistance to foreign bodies
- Non-return valve.

The 820 meter complies with the 2004/22/EC (MID), 75/33 (EEC), EN 14154, OIML R49, ISO 4064 and ISO 9001 specifications. It has a metering class of R200 and R160 for the horizontal and vertical installation.



Figure 6-16: Sensus 820 water meter (adapted from Sensus)

The 820 is available in 15mm and 20 mm sizes with a summary of the meter properties in Table 6-4.



Table 6-4: Sensus single-jet meters for advanced metering applications

Description	Symbol	Unit	120	120C	820
Metrologic Properties					
Meter Sizes	DN	mm	15	15	15 20
Meter Class	Q ₃ /Q ₁ or Other		R80 (Horizontal) R 40 (Vertical)	R80 (Horizontal) R 40 (Vertical)	R200 (Horizontal)/ R160 (Vertical)
Minimum Flow Rate	Q ₁	l/h	31 63	31 63	13 25
Transitional Flow Rate	Q ₂	l/h	50 100	50 100	20 40
Permanent Flow Rate	Q ₃	m ³ /h	2.5	2.5	3.125 5
Overload Flow Rate	Q ₄	m ³ /h	3.125	3.125	2.5 4
Meter Features and Capabilities					
Built-in valve			Non-return valve	Non-return valve	Non-return valve
SABS compliant			Not specified	Not specified	Not specified
Other standards meter complies with			75/33/EEC, 79/839/EEC, 2004/22/CE (MID), EN 14154, OIML R49, ISO 9001 and ISO 4064	2004/22/CE (MID), EN 14154, OIML R49 and ISO 4064	2004/22/EC (MID), 75/33 (EEC), EN 14154, OIML R49, ISO 4064 and ISO 9001
Any alarm features?			Not indicated	Not indicated	Not indicated
Meter Functionality					
Is it capable of remote communication?			Add-on	Add-on	Add-on
Does it have a battery?			Not indicated	Not indicated	Not indicated
What is the claimed lifespan?			N/A	N/A	N/A
Which communication technology?			Pulse or Radio communication	Pulse or Radio communication	Pulse or Radio communication



Does it have uni- / bi-directional communication?	AMR uni-directional communication	AMR uni-directional communication	AMR uni-directional communication
STS compliance	Not specified	Not specified	Not specified

Multi-jet meters

Sensus supplies two multi-jet models that can be used as advanced meters. These are the 405S meter and the 420/420PC meter. A summary of the properties of these meters is given in Table 6-5.

Sensus 405S meter

The 405S is a dry dial multi-jet meter with protected transmission between the measuring element and the totalizer. The 405S is stated to be reliable, noiseless when in operation and resistant to bad water quality. The 405S has a 355° swivelling register for easy readability.

Other features of the 405S include:

- The capability of the meter to be equipped with a HRI sensor. The HRI sensor will enable the 405S to be set up in an AMR network and read off remotely
- The ability to be equipped with a removable bonnet for quick and easy maintenance
- 355° swivelling register for easy readability
- High resistance to water impurities
- Insensitive to water impurities
- Non-return valve.

The 405S complies with the OIML R49, 75/33/EEC and ISO 4064 standards. It is available in 15mm to 40 mm sizes. Figure 6-17 below illustrates the Sensus 405S meter



Figure 6-17: Sensus 405S water meter (adapted from Sensus)

Sensus 420/420PC meter

The 420PC is a multi-jet meter intended for residential consumers. The 420 is a wet dial meter whereas the 420 PC is a protected semi-dry dial meter.

Stated features of the 420/420PC are:

- Tamper proof and robustness
- Non-return valve
- Can be equipped with a HRI interface through which the 420/420P has AMR capabilities.

The 420/420PC complies with the EEC 75/33/EEC and 71/316/EEC directives. The 71/316/EEC directive is the standard for meters measuring liquids other than water. Other standards the 420/420P conform to are the 2004/22/EC (MID), PN-ISO 14154 (the Polish version of ISO 14154), OIML R49 and ISO 4064 specifications. The metrological classes for the 420/420PC are R160, R80 and R40.

The 420/420PC is available in sizes ranging from 15mm to 40mm.



Figure 6-18: 420/420PC meter (adapted from Sensus)



Table 6-5: Sensus multi-jet meters for advanced metering applications

Description	Symbol	Unit	405S					420/420PC				
Metrologic Properties												
Meter Sizes	DN	mm	15	20	25	30	40	15	20	25	32	40
Meter Class	Q ₃ /Q ₁ or Other											
Minimum Flow Rate	Q ₁	l/h	20	30	50	90	150	16	25	39	63	100
Transitional Flow Rate	Q ₂	l/h	120	200	280	480	800	25	40	63	100	160
Permanent Flow Rate	Q ₃	m³/h	1.5	2.5	3.5	6	10	2.5	4	6.3	10	16
Overload Flow Rate	Q ₄	m³/h	3	5	7	12	20	3.125	5	7.875	12.5	20
Meter Features and Capabilities												
Built-in valve			Non-return valve specified for DN15 and DN20					Non-return valve				
SABS compliant			Not specified					Not specified				
Other standards meter complies with			75/33/EEC, OIML R49, ISO 9001 and ISO 4064					2004/22/CE (MID), EN 14154, OIML R49 and ISO 4064				
Any Alarm features?			Not indicated					Not indicated				
Meter Functionality												
Is it capable of remote communication?			Add-on					Add-on				
Does it have a battery?			Not indicated					Not indicated				
What is the claimed lifespan?			N/A					N/A				
Which communication technology?			Pulse or Radio communication					Pulse or Radio communication				
Does it have uni / bi-directional communication?			AMR uni-directional communication					AMR uni-directional communication				
STS compliance			Not specified					Not specified				

Positive displacement meters

Sensus supplies three positive displacement meter models that can be used as advanced meters. These are the 620/620M, the 620C/620MC and the 640C/640MC meters. A summary of the properties of these meters is given in Table 6-6.

Sensus 620/620M meter

The 620/620M is a high precision volumetric meter. It uses piston measuring chamber in which it's stated to detect drops of water. This is due to the material used to make the piston. Sensus states that the material has a density close to that of water and an enhanced finish that allows the piston to glide easily in the measuring chamber at low flows

Other features of the 620/620M includes the following

- AMR capabilities through the use of the HRI sensor the 620/620M can have.
- A non-return valve
- Tamper proof
- High resistance to impurities
- Quiet in operation
- High accuracy

The 620/620M complies with the 20048/22/EC (MID), EN 14154, OIML R49 and ISO 4064. This meter is available in sizes ranging from 15mm to 40mm, however, only metrological information of 15mm and 20mm sizes are available and shown in Table 6-6.



Figure 6-19: Images of the 620/620M water meters (adapted from Sensus)

Sensus 620C/620MC meter

The 620C/620MC is a high precision volumetric meter with a composite body that comprises of a dry dial. Like the 620/620M, the 620C/620MC uses a unique measuring chamber that is sensitive to low flow and drops of water.

Other features of the 620C/620MC are as follows:

- AMR capabilities through the HRI sensor
- Quiet in operation
- High resistance to impurities and aggressive water
- High accuracy and measuring range
- Tamper proof

The 620C/620MC complies with the following standards: 2004/22/EC (MID), EN 14154, OIML R49 and ISO 4064. As stated previously, Sensus South Africa states that all their products also comply with the ISO 9001. In accordance to the 2004/22/EC (MID) specifications, the 620C/620MC is capable of a meter class as high as R400.

The 620C/620MC is available in 15 mm and 20 mm. A summary of these meter properties is displayed in Table 6-6.



Figure 6-20: Images of the 620C/620MC meter (adapted from Sensus)

Sensus 640C/640MC meter

The 640C/640MC is a high precision volumetric meter with a composite body that includes an electronic register. Like the 620C/620MC, the 640C/640MC meter uses a unique measuring chamber that is sensitive to low flow and drops of water.

The 640C/640MC meter range includes an electronic register with an integrated radio functionality that enables remote communication. Due to this register, the 640C/640MC is capable of AMR and AMI bi-directional communication. The protection class of the electronic register of the 640C family is the IP68.

Other characteristics of the 640C/640MC are as follows:

- Light and robust
- Environmentally friendly
- Quiet in operation
- High accuracy and measuring range
- Ready for wireless communication
- Tamper proof
- An in-built battery, however the battery life is not stated.

The 640C/640MC meter complies with the 2004/22/EC (MID), OIML R49, EN 14154 and ISO 4064 specifications, and for South African products with the ISO 9001. In accordance with the 2004/22/EC (MID) specifications, the 640C/640MC is capable of a meter class as high as R400.

The 640C/640MC meter is available in 15mm and 20mm sizes.



Figure 6-21: Images of the 640C/640MC meter (adapted from Sensus)



Table 6-6: Sensus positive displacement meters for advanced metering applications

Description	Symbol	Unit	620/620M		620C/620MC		640C/640MC	
Metrologic Properties								
Meter Sizes	DN	mm	15	20	15	20	15	20
Meter Class	Q ₃ /Q ₁ or Other		Available in R40/R80/R160/R315/R400		Available in R40/R80/R160/R315/R400		Available in R40/R80/R160/R315/R400	
Minimum Flow Rate	Q ₁	l/h	6.3	10	6.25	10	6.25	10
Transitional Flow Rate	Q ₂	l/h	10	16	10	16	10	16
Permanent Flow Rate	Q ₃	m ³ /h	2.5	4	2.5	4	2.5	4
Overload Flow Rate	Q ₄	m ³ /h	3.125	5	3.125	5	3.125	5
Meter Features and Capabilities								
Built-in valve			Non-return valve		No		No	
SABS compliant			Not specified		Not specified		Not specified	
Other standards meter complies with			75/33/EEC, OIML R49, ISO 9001 and ISO 4064		2004/22/EC (MID), EN14154, OIML R49, ISO 9001 and ISO 4064		2004/22/CE (MID), EN 14154, OIML R49 and ISO 4064, ISO 9001	
Any Alarm features?			Not indicated		Not indicated		Not indicated	
Meter Functionality								
Is it capable of remote communication?			Add-on		Add on		In-built	
Does it have a battery?			Not indicated		Not Indicated		Yes	
What is the claimed lifespan?			N/A		Not indicated		Not indicated	
Which communication technology?			Pulse or radio communication		Pulse or radio communication		Radio communication	



Does it have uni- / bi-directional communication?	AMR uni-directional communication	AMR uni-directional communication	AMR/AMI uni-directional communication
STS compliance	Not specified	Not specified	Not specified

Solid-state meters

Sensus iPERL meter

The iPERL is a solid-state water meter with remnant magnetic field technology to measure the flow rate through the meter. The iPERL has both AMI and AMR communication capabilities. The iPERL was designed mainly to record information regularly and relay this information efficiently with special considerations for any discrepancies such as water leaks.

Features of the iPERL are as follows:

- Tamper proof and fraud resistant
- Has alarm functionality such as leak detection, tampering or abnormal usage reporting
- Capable of data capturing, and has an internal memory with a claimed capacity of 2880 data points which is equivalent of over one month of 15 minute resolution data
- Has bi-direction communication capability
- Stated to be highly accurate
- Has a battery with a claimed life span of 15 years.

The iPERL complies with the EN 14154, OIML R49 and in South Africa with ISO 9001 specifications. The meter class for the iPERL is R800 and is available in sizes ranging from 15mm to 40mm. A summary of the iPERL properties are displayed in Table 6-7.



Figure 6-22: Image of an iPERL meter (adapted from Sensus)



Table 6-7: Sensus solid state water meters for advanced metering applications

Description	Symbol	Unit	iPERL				
Metrologic Properties							
Meter Sizes	DN	mm	15	20	25	30	40
Meter Class	Q ₃ /Q ₁ or Other		R800				
Minimum Flow Rate	Q ₁	l/h	3.13	5	7.88	12.5	20
Transitional Flow Rate	Q ₂	l/h	5	8	12.6	20	32
Permanent Flow Rate	Q ₃	m ³ /h	2.5	4	6.3	10	16
Overload Flow Rate	Q ₄	m ³ /h	3.125	5	7.875	12.5	20
Meter Features and Capabilities							
Built-in valve			No				
SABS compliant			Not indicated				
Other standards meter complies with			EN 14154, OIML R49 and ISO 9001				
Any Alarm features?			Leak detection, tamper detection, abnormal flow detection				
Meter Functionality							
Is it capable of remote communication?			In-built				
Does it have a battery?			Yes				
What is the claimed lifespan?			15 years				
Which communication technology?			Radio communication, RF and Wi-Fi mesh network				
Does it have uni- / bi-directional communication?			Bi-direction AMR/AMI				
STS compliance			Not indicated				



A.3.3 Supporting infrastructure

High Resolution Interface

High Resolution Interface (HRI) is a universal sensor that is compatible with a wide range of meters, including single-jet, multi-jet piston meters with dry-dial and semi-dry registers in glass-copper or plastic housing.

The HRI can be retrofitted on all Sensus meters built since 2008 that are pre-equipped with an HRI modulator.

The HRI is available in two versions:

- The HRI-A pulse unit is a high resolution pulser which detects the flow direction
- The HRI-B data unit is an electronic register with a data interface which supports both hard-wired M-Bus systems and battery-driven MiniBus devices such as mobile meter reading systems. The HRI-B can alternatively be used as a pulse type with configurable pulse output.

Typical application of the HRI include:

- Load profiles via a fixed network using M-Bus or via radio, telephone or GSM modem
- Industrial application (e.g. dosing)
- Remote reading of flow rate and cumulative flow using a frequency converter
- Leakage detection when connected to a data logger
- Generation and transmission of flow profiles using a data logger and GSM modem. The design of the HRI allows the system to be installed in extreme conditions, such as flooded meter pits.

Features of the HRI sensor include:

- Load-free sensor detection of the pointer's rotation of pre-equipped meters
- No influence to the meter performance
- Detects flow direction
- Suitable for a wide range of meters and can be retrofitted to pre-equipped meters
- Internal battery, however no claimed life span
- Hermetically sealed housing (IP68)

- Non-magnetic principle.

A.4 Itron

A.4.1 Introduction

Company background

Itron is a global technology and services company dealing with energy and water metering technologies; it offers solutions that measure, manage and analyse energy and water. The company has been in existence for over 100 years and operates in more than 100 countries

Product Ranges

Itron has a range of technologies such as conventional meters, advanced meters and add-ons that give metering systems additional function such as automatic meter reading (AMR) and advanced metering infrastructure (AMI). Most of the Itron products are aimed at proactive water demand management.

A.4.2 Water meters

Flodis

Flodis is single-jet turbine type meter, designed to measure cold drinking water and offering the capability to accurately measure a wide range of flow rates. According to the manufacturer, Flodis has a simple engineered design, enabling accurate measuring of low flowrates up to peak flows over time. It is considered as a Class C meter. A summary of the Flodis properties are illustrated in Table 6-8.

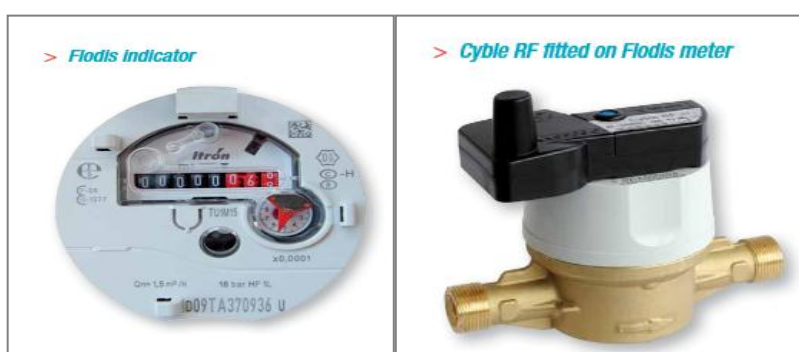


Figure 6-23 : Image of an Flodis

The Flodis single-jet meter is pre-equipped with Cyble technology for communication.



Flodis has two main components: the hydraulic that allows measurement of the water flow and the register that displays the measured water volume. The transmission interface between those components is achieved by a magnetic coupling. Flodis is a single-jet velocity meter. Flow coming from the inlet is diverted by a specially shaped injector that drives the turbine. This technology is suitable for all types of water quality distribution. Equipped with an upstream filter, Flodis is protected against impurities accidentally conveyed by water. The magnetic coupling transmission, standard on the Flodis line, is accompanied by an extra-dry register. Both gears and register are in a waterproof and airproof enclosure. The turbine is the only moving part of the meter in motion in water.

According to the manufacturer, Flodis is linked to a Cyble technology comes with the following advantages:

- Leakage detection
- Reverse flow management
- Consumption profile analysis
- Immune to magnetic tampering
- Principle proven on the field with 20 years' experience.



Table 6-8: Advanced metering applications of Itron's Flodis

Description	Symbol	Unit	Flodis			
Metrologic Properties						
Meter Sizes	DN	mm	15	20	25	32
Meter Class	Q ₃ /Q ₁ or Other		R160			
Minimum Flow Rate	Q ₁	l/h	15.6	25	39.4	62.5
Transitional Flow Rate	Q ₂	l/h	25	40	63	100
Permanent Flow Rate	Q ₃	m ³ /h	2.5	4	6.3	10
Overload Flow Rate	Q ₄	m ³ /h	3.1	5	7.9	13
Meter Features and Capabilities						
Built-in valve			No			
SABS compliant			Not indicated			
Other standards meter complies with			ISO 4064			
Any Alarm features?			No			
Meter Functionality						
Is it capable of remote communication?			Add-on			
Does it have a battery?			Yes			
What is the claimed lifespan?			15 years			
Which communication technology?			Pulse transmitter or integrated radio technology			
Does it have uni / bi-directional communication?			Bi direction AMR/AMI			
STS compliance			Not indicated			

A.5 Aquiba

A.5.1 Overview

Aquiba is a joint venture between two established companies, Sentec and Takahata Precision. Sentec, situated in Cambridge, UK, is the internationally renowned supplier of advanced grid and metering technology, specializing in world class advanced metering solutions for water, gas and electricity. Takahata Precision is a Japanese owned, worldwide manufacturing company with widespread expertise in mechanical design, high precision molding and product assembly for demanding applications.

A.5.2 Aquiba A200 meter

Overview

The Aquiba A200 DN20 is an AMI, mag-flow water meter designed for residential use. The A200 consists of a highly accurate sensor, powerful processor, bi-directional ZigBee communication capabilities and a data archive.



Figure 6-24: Image of an Aquiba A200 (adapted from Aquiba)

Operations and functionality

Residential sensor technology accurately measures flow at all flow rates relevant to revenue collection. The processor stores time-stamped readings in the archive and can run additional applications in real time to convert high volumes of data into discrete items of information. Data can be extracted via the optical port and certain information can be retrieved by radio (as supported by bi-directional ZigBee SEP 1.0).



The A200's secure optical port allows connection of an optical reader programmer (ORP) to allow for easy programming and data retrieval. The ORP simply clips onto the top of the meter and is held in place by magnets.

Data is transferred via USB cable to a PC running Aquiba Meter Explorer software. This software enables installation, configuration, commissioning and maintenance of the A200. It also performs basic data visualization and allows consumption data to be exported to third party applications for additional analysis.

Features and specifications

The features and specifications of the Aquiba A200 meter are as follows:

- Fully static mag-flow technology
- Accurate at all flow rates, over full service life
- No moving parts – no wear or jamming
- Eliminates under-registration issue
- High resolution, time-stamped data securely stored in data archive
- Low lifetime cost and low environmental impact
- Battery life claimed to be 15 years
- Factory refurbishable for extended operation
- Supports network and household leakage detection
- Secure ZigBee SEP 1.0 radio
- Field upgradeable firmware
- Generous processor and memory capacity for additional applications.

A.6 Landis+Gyr

A.6.1 Overview

Landis+Gyr are a global industrial company with metering solutions for electricity, gas and water for energy measurement solutions for utilities. Landis+Gyr was founded in 1896 in Zug, Switzerland, as an electricity metering company. Like the above-mentioned companies, they have developed into an internationally recognized company with developments in the field of advanced metering.

A.6.2 Gridstream RF Water Module meter

Overview

The Gridstream RF Water Module is a two-way, AMI device that enables near real-time access to critical water assets. The module logs water consumption values for each interval and transmits the data across the network four times per day. The Gridstream RF Water Module is a component that is connected to a conventional meter to make it an advanced meter.

Landis+Gyr has developed three different types of RF Water Modules that give users a variety of means to connect the module to existing water meters as well as different means of sending information. These are as follows:

- Gridstream RF interpreter
- Gridstream RF wall mount
- Gridstream RF pit.

A.6.3 Gridstream RF Interpreter

The Gridstream RF Interpreter is easily mounted without disrupting the existing meter and deployed over the network. There are no wires and the radio and the encoder are sealed within a single unit for added security and durability. Figure 6-25 shows an example of an RF Interpreter:



Figure 6-25: An example of an RF Interpreter (adapted from Landis+Gyr)

Gridstream RF Water Wall Mount

The wall module quickly and easily connects to most existing three-wire water meter encoders and is deployed over the Gridstream network. Figure 6-26 shows an example of an RF wall mount:



Figure 6-26: An example of an RF Wall Mount (adapted from Landis+Gyr)

Gridstream RF Pit

The Gridstream RF pit module can be easily installed and directly connected to an existing three-wire encoder and deployed over the Gridstream network. Figure 6-27 shows an example of an RF pit module:



Figure 6-27: An example of an RF Pit Module (adapted from Landis+Gyr)

Features and specifications

- Leverages full potential and scalability of Gridstream AMI network
- No costly infrastructure add-ons required
- Supports advanced capabilities such as leak detection, reverse flow, tampering and theft
- Easily connects to an existing encoder without service interruption
- Plug-and-play activation keeps deployment, on schedule



- Interoperable for future advancements in water measurement
- Two 3.6 volt AA Thionyl Chloride Lithium batteries with advanced power life management design
- Data is transmitted every 6 hours
- Each transmission includes register read and last 24 hours of 15-minute interval data
- Battery life is claimed to be 20 years.



B SURVEY QUESTIONNAIRE

B.1 Questionnaire template

B.1.1 Introduction

The University of Cape Town is conducting a study funded by the Water Research Commission (WRC) on the application of advanced water metering in South Africa. Advanced metering includes all water meters with added functionality, for instance pre-payment or automatic meter reading capability.

This questionnaire is completed for a single project. Please select the most appropriate project if you have been involved in several, or complete different questionnaires for different projects. Please estimate values as well as you can, but leave out answers you don't know the answer to.

You are free not to participate or stop participating at any time. You may also remain anonymous if you choose. However, if you are willing to share your name and contact information, this will allow us to contact you in future should we have further queries. Your name and contact details will remain confidential at all times.

1.1	Name (optional)	
1.2	Position (optional)	
1.3	Employer (optional)	
1.4	Contact number (optional)	

B.1.2 Your experience with advanced metering projects

2.1	What was the name of the advanced metering project that you were involved in?
2.2	Where was it situated?
	Province: _____ City/Town/Rural Area: _____
2.3	What type of advanced metering project was it?



	<input type="radio"/> Prepaid <input type="radio"/> AMR <input type="radio"/> Data Management Other: _____
2.4	Who was the advanced metering project done for?
	<input type="radio"/> NGO <input type="radio"/> SA Municipality <input type="radio"/> SA bulk water supplier <input type="radio"/> Non-SA institution Other: _____
2.5	What was your role in the project?
	<input type="radio"/> Technical Designer <input type="radio"/> Meter Supplier Representative <input type="radio"/> Community Liaison <input type="radio"/> Construction <input type="radio"/> Operations & Maintenance <input type="radio"/> Observer <input type="radio"/> Project management Other: _____
2.6	Who were you employed by?
	<input type="radio"/> NGO <input type="radio"/> SA Municipality <input type="radio"/> SA bulk water supplier <input type="radio"/> Non-SA institution <input type="radio"/> Consultant <input type="radio"/> Contractor Other: _____
2.7	Year of Implementation

B.1.3 System Parameters

3.1	What type of consumer were provided with the metering system?
	<input type="radio"/> Domestic – High Income <input type="radio"/> Domestic – Low Income <input type="radio"/> Industrial <input type="radio"/> Commercial Other: _____
3.2	What was the development type?
	<input type="radio"/> Formal Urban <input type="radio"/> Formal Rural <input type="radio"/> Informal Settlements <input type="radio"/> Private Development



	Other: _____
--	--------------

B.1.4 Project Parameters

4.1	How many formal and/or informal properties were provided with advanced meters?
	Formal: _____ Informal: _____
4.2	What is the production cost of water for the municipality (in R per kl)?
4.3	What is the average water price charged to consumers (in R per kl)? (if a block tariff is used, select a tariff that would represent the average price)
4.4	If some consumers are charged a fixed monthly service fee, what is the water supply part of this fee (in R)?
4.5	What is the average household income (in R per month)?
4.6	What is the unemployment rate? (%)
4.7	What is the fraction of adults with a Grade 12 or higher qualification? (%)
4.8	What was the main reason for implementing the advanced metering project
	<input type="radio"/> Cost Recovery <input type="radio"/> Debt Recovery <input type="radio"/> Leakage Detection <input type="radio"/> Demand Management Other: _____
4.9	What is the free basic water allowance (kL/month)?
4.10	What fraction of the supply area get free basic water (%)?



B.1.5 Provide the following information for the system both before and after the advanced metering project was implemented:

		Before	After
5.1	What is the fraction of properties where consumers are:		
	Billed based on metered consumption (%):		
	Billed a fixed rate for water (%):		
	Not billed for water at all (%):		
	Illegal connections (%):		
	Total (should be 100%)		
5.2	Average monthly consumption estimate for properties where consumers are:		
	Billed based on metered consumption (kL):		
	Billed a fixed rate for water (kL):		
	Not billed for water at all (kL):		
	Illegal connections (kL):		
5.3	Fraction of properties paying for water that are:		
	Billed based on metered consumption (%):		
	Billed a fixed rate for water (%):		
5.4	Fraction of demand that is on-site leakage (%):		
5.5	Frequency of meter readings [monthly; bi-monthly; every 3 months; other: _____]		
5.6	Average no of incidences of community protest or mass action per year:		



		Before	After
5.7	Fraction of meters failing annually due to:		
	Water meter failure (%):		
	Electronics and other component (e.g. valve) failure (%):		
	Vandalism (%):		
5.8	Estimated costs for the following components:		
	Meter purchase (R/meter)		
	Installation (R/meter)		
	Battery replacement (including battery and installation) (R/replacement):		
	Total cost for required communication infrastructure		
	Total cost for required payment infrastructure		
	Meter reading (R/meter)		
	Operation and maintenance (R/month)		
	Debt-recovery for water services for the study area: (R/year)		
	Other costs (R/meter): _____		
5.9	How many of the following staff would this system have ideally had to operate and maintain it adequately (use fractions for part of a person's time if applicable):		
	Plumbers:		
	Specialist meter technicians:		

B.1.6 Please provide information of the following parameters for the advanced water meters used in the project:

6.1	Advanced meter make and model used:
6.2	Battery life claimed by manufacturers:



6.3	Average battery life experienced:
6.4	Minimum and maximum battery lives experienced:

B.1.7 Other interviewees:

7.1	Please provide us with names and contact details of other persons we can approach with this questionnaire.

B.2 Data collected

This section shows the data acquired from surveys on practitioners and experts in water metering and distribution field. In total, 22 surveys were conducted. Only 10 surveys pertained to high income areas and 5 contained sufficient data.

The data collected was grouped based on the type of development of the project. They are as follows:

- Formal urban
- Industrial development
- Private development

B.2.1 Formal urban



Details		Interviewee A	Interviewee B	Interviewee C
2. Experience with advanced meters				
2,1	Name of AWM project	AMR	National Work Company	Installation of AMR and Prepaid metering
2,2	Location	KZN (Durban)	Saudi Arabia (Riyadh)	Free State (Bloemfontein)
2,3	Type of AWM project	AMR	AMR	Prepaid and AMR
2,4	Owner of AWM project	SA bulk water supplier	Non-SA institution	SA Municipality
2,5	Role played in project	Operation and maintenance	Technical Designer and Meter Supplier Representative	Project management
2,6	Employer	SA bulk water supplier	Independent Smart Grid Supplier	SA Municipality
2,7	Year of Implementation	2014	2013-2015	2014-15 to 2017-18
3. System parameters				
3,1	Type of consumer	Municipality Distribution system	Domestic High Income	Domestic High Income and Domestic Low Income
3,2	Type of development	Formal Urban	Formal Urban	Formal Urban
4. Proposed parameters				
4,1	Number of formal properties	12	80 000	2800
	Number of informal properties	6	-	-
4,2	Water production cost	-	-	-
4,3	Average water price (R/kl)	-	-	12
4,4	Amount of fixed monthly service fee	-	-	-
4,5	Average household income (R/month)	-	20 000	4 000



4,6	Unemployment rate (%)	-	0	30			
4,7	fraction of adults with Grade 12 or higher	-	-	40			
4,8	Main Reason for AWM implementation	Demand Management	Demand Management	Cost recovery, Leak detection, demand management			
4,9	FBW (Kl/month)	-	0	10			
4,10	Fraction of supply area getting FBW (%)	-	0	-			
5. System information before and after implementation							
5,1	Fraction of properties where consumers are:	Before	After	Before	After	Before	After
	Billed based on metered consumption (%)	-	-	80	80	-	-
	Billed a fixed rate for water (%)	-	-	20	20	-	-
	Not billed for water at all (%)	-	-	-	-	-	-
	Illegal connections (%)	-	-	-	-	-	-
	Total (should be 100%)	-	-	100	100	-	-
5,2	Average monthly consumption for properties where:	-					
	Billed based on metered consumption (KL)	-	-	-	-	-	-
	Billed a fixed rate for water (KL)	-	-	-	-	-	-
	Not billed for water at all (KL)	-	-	N/A	-	-	-
	Illegal connections (KL)	-	-	N/A	-	-	-
5,3	Fraction of properties paying for water						



	Billed based on metered consumption (%)	-	-	80	80	25	-
	Billed a fixed rate for water (%)	-	-	20	20	-	-
5,4	Fraction of demand that is onsite leakage (%)	-	-	-	-	-	10
5,5	Frequency of meter readings	-	-	monthly	N/A	-	-
5,6	Average no. of incidences of community protest	-	-	N/A	N/A	-	-
5,7	Fraction of meters failing annually due to:	-	-			-	-
	Water meter failure (%)	-	-	30	2	-	-
	Electronics and other components (%)	-	-	-	-	-	-
	Vandalism	-	-	-	-	-	-
5,8	Estimated cost for the following components						
	Meter purchase (R/meter)	-	-	750	2000	300	1000
	Installation (R/meter)	-	-	-	-	800	800
	Battery replacements (including installation) (R/replacements)	-	-	N/A	N/A	-	-
	Total cost for required communication infrastructure	-	-	N/A	10 000 000	-	-
	Total cost for required payment infrastructure	-	-	-	-	-	-
	Meter Reading (R/meter)	-	-	-	-	12	12



	Operation and maintenance (R/month)	-	-	-	-	-	-
	Debt-recovery for water services for study area (R/year)	-	-	-	-	-	-
	Other costs (R/meter)	-	-	-	-	-	-
5,9	Staff requirements						
	Plumbers	-	-	-	-	60	100
	Specialist meter technicians	-	-	-	-	10	20
6,1	AWM make and model used	-		iPERL Sensus		Elster Kent and Utility Systems	
6,2	Battery life claimed by manufacturers	-		15		10	
6,3	Average battery life experienced	-		>15		-	
6,4	Minimum and maximum battery lives experienced	-		> 15		-	



B.2.2 Industrial development



C SENSITIVITY ANALYSIS TABLES

The tables presented in this section illustrate how changes in parameter from low to high value for both proposed parameters induces a change on each key result

C.1 Changes in capital payment period due to change in input parameter value for both proposed metering system

Framework parameter	Conventional			Advanced		
	Low	Typical	High	Low	Typical	High
2. Global Parameters						
2.1. No of properties	134.8	134.8	134.8	-186.9	-72.5	-62.3
2.2. Water cost price	-68.1	134.8	43.1	-42.9	-72.5	-143.0
2.3. Applicable Water Tariff	46.2	134.8	-186.4	-230.7	-72.5	-44.8
3. Current system parameters						
3.1. BMC properties	134.8	134.8	134.8	-73.5	-72.5	-72.1
3.2. BMC unit consumption	-113.1	134.8	21.1	-56.5	-72.5	-222.3
3.3. Illegal or unbilled connections	134.8	134.8	134.8	-72.5	-72.5	-72.5
3.6. BMC payment rate	114.1	134.8	211.0	-77.5	-72.5	-64.2
3.9. On-site leakage	134.8	134.8	134.8	-72.5	-72.5	-72.5
4. Proposed system parameters						
4.5. Mean battery lifespan	-	-	-	-65.8	-72.5	-73.5
4.7. Meter service life	134.8	134.8	134.8	-72.5	-72.5	-72.5
4.8. Effective service life	134.8	134.8	134.8	-72.5	-72.5	-72.5
4.9. Water meter failure rate	93.0	134.8	244.6	-90.5	-72.5	-60.4
4.10. Electronics and other components failure	-	-	-	-103.4	-72.5	-60.4
4.11. Vandalism	115.3	134.8	187.2	-76.3	-72.5	-69.0
4.14. Meter price	113.4	134.8	163.0	-68.2	-72.5	-76.1
4.15. Installation cost	63.8	134.8	184.3	-65.3	-72.5	-76.1
4.16. Communication infrastructure cost	-	-	-	-64.8	-72.5	-84.0
4.17. Payment infrastructure cost	-	-	-	-71.7	-72.5	-73.6
4.18. Battery replacement cost	-	-	-	-73.9	-72.5	-71.1
4.19. Meter reading cost	111.1	134.8	267.4	-78.3	-72.5	-65.6
4.20. Meter operation and maintenance cost	84.7	134.8	-736.4	-100.7	-72.5	-46.4
4.21. Billing cost	78.8	134.8	463.4	-72.7	-72.5	-71.9
4.21. Average time of meter reading	311.5	134.8	113.3	-59.2	-72.5	-75.3



C.2 Changes in effective surplus due to change in input parameter value for both proposed metering system

Framework parameter	Conventional			Advanced		
	Low	Typical	High	Low	Typical	High
2. Global Parameters						
2.1. No of properties	R 343.81	R 3,438.11	R 17,190.56	-R 33,200.28	-R 208,259.25	-R 986,296.25
2.2. Water cost price	-R 37,301.89	R 3,438.11	R 32,538.11	-R 297,887.25	-R 208,259.25	-R 144,239.25
2.3. Applicable Water Tariff	R 29,634.58	R 3,438.11	-R 20,132.89	-R 119,213.25	-R 208,259.25	-R 288,400.65
3. Current system parameters						
3.1. BMC properties	R 3,190.00	R 3,438.11	R 3,544.44	-R 194,222.50	-R 208,259.25	-R 214,275.00
3.2. BMC unit consumption	-R 26,534.89	R 3,438.11	R 77,061.11	-R 244,915.55	-R 208,259.25	-R 120,755.55
3.3. Illegal or unbilled connections	R 3,438.11	R 3,438.11	R 3,438.11	-R 208,252.78	-R 208,259.25	-R 208,252.78
3.6. BMC payment rate	R 5,911.61	R 3,438.11	-R 1,508.89	-R 199,849.35	-R 208,259.25	-R 225,079.05
3.9. On-site leakage	R 3,438.11	R 3,438.11	R 3,438.11	-R 208,252.78	-R 208,259.25	-R 208,252.78
4. Proposed system parameters						
4.5. Mean battery lifespan	-	-	-	-R 221,462.03	-R 208,259.25	-R 206,373.14
4.7. Meter service life	-R 17,039.67	R 3,438.11	R 7,533.66	-R 286,675.92	-R 208,259.25	-R 169,050.92
4.8. Effective service life	-R 17,039.67	R 3,438.11	R 7,533.66	-R 391,231.48	-R 208,259.25	-R 169,050.92
4.9. Water meter failure rate	R 9,581.44	R 3,438.11	-R 2,705.22	-R 182,392.58	-R 208,259.25	-R 234,125.92
4.10. Electronics and other components failure	-	-	-	-R 169,459.25	-R 208,259.25	-R 234,125.92
4.11. Vandalism	R 5,741.86	R 3,438.11	-R 401.48	-R 201,792.59	-R 208,259.25	-R 214,725.92
4.14. Meter price	R 5,054.78	R 3,438.11	R 1,282.55	-R 149,453.00	-R 208,259.25	-R 327,084.25
4.15. Installation cost	R 8,827.00	R 3,438.11	-R 334.11	-R 153,696.75	-R 208,259.25	-R 264,640.50
4.16. Communication infrastructure cost	-	-	-	-R 199,925.92	-R 208,259.25	-R 220,759.25



4.17. Payment infrastructure cost	-	-	-	-R 207,425.92	-R 208,259.25	-R 209,509.25
4.18. Battery replacement cost	-	-	-	-R 205,834.25	-R 208,259.25	-R 210,684.25
4.19. Meter reading cost	R 6,348.11	R 3,438.11	-R 3,351.89	-R 198,559.25	-R 208,259.25	-R 221,839.25
4.20. Meter operation and maintenance cost	R 11,508.51	R 3,438.11	-R 12,741.49	-R 171,884.25	-R 208,259.25	-R 281,009.25
4.21. Billing cost	R 13,138.11	R 3,438.11	-R 6,261.89	-R 207,774.25	-R 208,259.25	-R 209,229.25
4.21. Average time of meter reading	-R 4,321.89	R 3,438.11	R 6,024.77	-R 237,359.25	-R 208,259.25	-R 203,409.25



C.3 Changes in effective surplus due to change in input parameter value for both proposed metering system

Framework parameter	Low	Typical	High
2. Global Parameters			
2.1. No of properties	19	194	970
2.2. Water cost price	194	194	194
2.3. Applicable Water Tariff	194	194	194
3. Current system parameters			
3.1. Billed metered consumption (BMC)	180	194	200
3.2. BMC unit consumption	194	194	194
3.3. Illegal or unbilled connections	194	194	194
3.6. BMC payment rate	194	194	194
3.9. On-site leakage	194	194	194
4. Proposed system parameters			
4.5. Mean battery lifespan	647	194	129
4.7. Meter service life	194	194	194
4.8. Effective service life	194	194	194
4.9. Water meter failure rate	194	194	194
4.10. Electronics and other components failure	194	194	194
4.11. Vandalism	194	194	194
4.14. Meter price	194	194	194
4.15. Installation cost	194	194	194
4.16. Communication infrastructure cost	194	194	194
4.17. Payment infrastructure cost	194	194	194
4.18. Battery replacement cost	194	194	194
4.19. Meter reading cost	194	194	194
4.20. Meter operation and maintenance cost	194	194	194
4.21. Billing cost	194	194	194
4.24. Average time of meter reading	194	194	194



C.4 Changes in reduction in consumption due to change in input parameter value for both proposed metering system

Framework parameter	Conventional			Advanced		
	Low	Typical	High	Low	Typical	High
2. Global Parameters						
2.1. No of properties	291	2 910	14 550	989	9 894	49 470
2.2. Water cost price	2 910	2 910	2 910	9 894	9 894	9 894
2.3. Applicable Water Tariff	2 910	2 910	2 910	9 894	9 894	9 894
3. Current system parameters						
3.1. Billed metered consumption (BMC)	2 700	2 910	3 000	9 180	9 894	10 200
3.2. BMC unit consumption	5 820	2 910	0	14 065	9 894	4 365
3.3. Illegal or unbilled connections	2 910	2 910	2 910	9 894	9 894	9 894
3.6. BMC payment rate	2 910	2 910	2 910	9 894	9 894	9 894
3.9. On-site leakage	2 910	2 910	2 910	9 894	9 894	9 894
4. Proposed system parameters						
4.5. Mean battery lifespan	-	-	-	9 894	9 894	9 894
4.7. Meter service life	2 910	2 910	2 910	9 894	9 894	9 894
4.8. Effective service life	2 910	2 910	2 910	9 894	9 894	9 894
4.9. Water meter failure rate	2 910	2 910	2 910	9 894	9 894	9 894
4.10. Electronics and other components failure	-	-	-	9 894	9 894	9 894
4.11. Vandalism	2 910	2 910	2 910	9 894	9 894	9 894
4.14. Meter price	2 910	2 910	2 910	9 894	9 894	9 894
4.15. Installation cost	2 910	2 910	2 910	9 894	9 894	9 894
4.16. Communication infrastructure cost	-	-	-	9 894	9 894	9 894
4.17. Payment infrastructure cost	-	-	-	9 894	9 894	9 894
4.18. Battery replacement cost	-	-	-	9 894	9 894	9 894
4.19. Meter reading cost	2 910	2 910	2 910	9 894	9 894	9 894
4.20. Meter operation and maintenance cost	2 910	2 910	2 910	9 894	9 894	9 894
4.21. Billing cost	2 910	2 910	2 910	9 894	9 894	9 894
4.21. Average time of meter reading	2 910	2 910	2 910	9 894	9 894	9 894